NEW ZEALAND
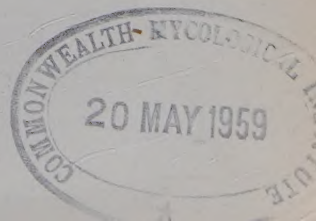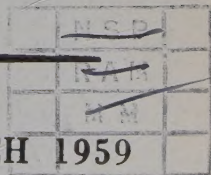# JOURNAL
OF
SCIENCE

NOTICE TO CONTRIBUTORS

General

Papers published, or offered for publication, elsewhere are not acceptable. Nevertheless, publication elsewhere of an abstract or of an extended summary does not preclude publication in full in this journal.

Typescript

The original and one carbon copy are required, on one side only of foolscap paper, double spaced, with a left-hand margin of at least one inch and a quarter. Reasonably heavy good-quality paper should be used. flimsy paper delays the machine operator and consequently increases the cost of printing.

A brief summary is required, at the beginning of the paper. It should indicate the scope of the paper and give the principal results, and should be suitable for reproduction by abstracting journals as it stands.

All matter to be printed in italic type (e.g., generic and specific names) must be underlined.

Tables

Tabular matter costs more to print than letterpress and should therefore be kept to a minimum, bearing in mind, however, that a well-planned table can take the place of a much greater area of letterpress.

Wherever possible, tables should be arranged to fit upright on the page, not sideways. They will be printed in 8-point type.

All tables, however brief, should be numbered in arabic numerals. Numerous very small tables should be avoided.

Titles should be as brief as possible.

Units of measurement should be placed in parentheses at the head of the column, not in the body of the table. Descriptive notes should be kept to the minimum, and abbreviations used wherever possible. For abbreviations, etc., the usage followed is that of British Standard 1991, Letter Symbols, Signs, and Abbreviations. Part 1. General.

Figures

These are to be numbered consecutively in arabic numerals, regardless of whether they are half-tones (photographs) or line blocks (graphs, etc.). Each must be referred to in the text, and only such figures as are essential to elucidate the text can be published.

The author's name, the title of the paper (abbreviated), and the figure number should be written lightly in soft pencil on the back of each figure.

Photographic prints should be on glossy paper, and may be the same size as or larger than the printed picture. Components of a composite figure should be firmly mounted on white card, and lettered as required A. B. C. etc.

Graphs should preferably be drawn about twice the final size, with the curves evenly inked throughout. Great care should be taken to ensure that all detail, especially lettering, is of such size as to be clearly legible when reduced to the final size. If he wishes, the author may insert lettering in pencil for re-draughting in this office.

If the scale is important, it should be shown on the figure, or, alternatively, the magnification or reduction may be stated in the caption, taking into account the printing reduction.

The figure number should not be given on the figure itself, only in the caption. Captions for all figures should be typed together at the end of the paper.

References

In the text, citations are to be by author's name and year, e.g. "(Brown, 1957)" or " . . . as stated by Brown (1957)". The list of references at the end of the paper is to be arranged in alphabetical order of authors' names Titles of papers cited may be included or omitted; if included, all words other than conjunctions, pronouns, and prepositions are to have capital letters. Titles of periodicals are to be abbreviated in accordance with the "World List of Scientific Periodicals", 3rd ed. 1952. The title of the periodical and the volume (and part) number are to be underlined for italics, but not the page number(s). Titles of books are to be inverted commas and not underlined; the name and location of the publisher are to be given. For arrangement, punctuation, etc., of references, see examples in this issue.

SPECIES OF *Eriococcus* Targ. (Homoptera, Coccoidea) ASSOCIATED WITH THE GENUS *Leptospermum* Forst. IN SOUTH-EASTERN AUSTRALIA AND TASMANIA

By J. M. Hoy, Entomology Division, Department of Scientific and Industrial Research, Palmerston North

Summary

A survey was undertaken in an attempt to find the original habitat of *Eriococcus orariensis* Hoy, the coccid responsible for the death of large areas of *Leptospermum scoparium* Forst. in New Zealand.

It has been established that *E. orariensis* is the most frequently encountered species of Coccoidea on *Leptospermum* in coastal areas from southern Queensalnd to South Australia and in Tasmania. In addition to *E. orariensis*, six other species in the genus *Eriococcus* were collected. *E. leptospermi* Maskell was known to occur on *Leptospermum*. *E. spiniger* Maskell is recorded from *Leptospermum* for the first time. Species described as new to science are *E. campbelli*, *E. cultellus*, *E. gibbus*, and *E. milleri*.

The principal *Eriococcus* species encountered were *E. orariensis* and *E. campbelli*, these insects being most frequently associated with *L. juniperinum* in mainland areas and *L. scoparium* in Tasmania. *E. orariensis* does not appear to be particularly harmful to its host species in Australia. If the writer had to select a species of *Eriococcus* for use against *L. scoparium* in New Zealand he would have chosen *E. campbelli*; this species, although encountered less frequently than *E. orariensis* was more often involved with the death of its host plant.

Both *E. orariensis* and *E. campbelli* support an extensive complex of parasites and predators. A number of areas suitable for parasite investigations were selected in case an attempt to control *E. orariensis* in New Zealand has to be made at some future date.

Introduction

A survey of species of *Eriococcus* associated with the genus *Leptospermum* in Australia was undertaken in an attempt to find the original habitat of *Eriococcus orariensis* Hoy. This coccid has been responsible for the death of large areas of *Leptospermum scoparium* Forst. throughout New Zealand (Hoy, 1954a). The possible origin of *E. orariensis* has been briefly discussed in an earlier paper (Hoy, 1954b). The insect was first noted attacking *L. scoparium* in the upper Orari River basin, Canterbury, about 1937. By 1945 *E. orariensis* was present on all stands of *Leptospermum* within a radius of approximately 20 miles. If the species was endemic it had previously been held at low population levels either by the presence of parasites and predators and/ or prevailing ecological factors. Extensive New Zealand-wide surveys conducted over the last 10 years have not revealed the presence of any insect parasites although recently a species of parasitic fungus has been found in East Coast districts of the North Island. Climatic conditions appear to have little effect on the establishment of *E. orariensis* since it can be found on *Leptospermum* in the South Island up to the altitudinal limit for the host plant. This ability to survive under a wide range of ecological conditions negates the suggestion that *E. orariensis* had, in the past, been held in check by ecological factors. All the available evidence pointed to the fact that this coccid was a comparatively recent introduction from overseas.

Reasons for Conducting Survey in Australia

The first step in establishing the origin of *E. orariensis* was to send specimens to entomological institutions in England, America, and Australia. In no case could the insect be identified. The possibility that the coccid had been introduced could not be discarded, in spite of the lack of knowledge of the species overseas, as the coccid fauna of most countries is imperfectly known.

If it were presumed that *E. orariensis* was an introduced species, a number of factors could be investigated which would provide clues as to its original habitat. Over recent years there has been a large interchange in ornamental varieties of *L. scoparium* between New Zealand, United States, Canada, and Australia. An investigation of the host specificity of the insect could eliminate those countries in which affected plant genera did not occur naturally. This question of host specificity has received careful attention ever since the problem has been under investigation. There are no known cases within New Zealand of *E. orariensis* establishing on any hosts outside the genus *Leptospermum*. This suggested that only those countries in which *Leptospermum* occurred naturally need be considered in the search for the original habitat.

The genus *Leptospermum* contains approximately 30 species, mostly Australian but also in New Zealand, New Caledonia, and Malaya (Curtis, 1956). Thus, Australia appeared the logical area to survey first for the presence of *E. orariensis*.

Two modes of entry into New Zealand would be available to an insect of this nature. Either it had been introduced on imported plants of *Leptospermum*, or it had been wind-borne into the country as first instar nymphs. If the latter explanation were correct, the south-eastern coast of the Australian mainland or Tasmania would be possible points of origin. A number of facts tended to support this hypothesis.

E. orariensis was first reported in New Zealand in a relatively isolated locality, the upper Orari River basin. The artificial transfer of infected ornamental varieties into such an area would be difficult to envisage as the initial establishment site was remote from domestic gardens. The presence of the insect on the host plant can readily be detected by the copious amount of black mould growing on "honey dew" produced by the coccid. An infected plant could readily be detected in the nursery.

A closely related Australian species, *Eriococcus leptospermi* Mask. was found in another isolated area, the Conway River valley, during 1949 (Hoy, 1953). The intensive surveys being conducted on the distribution of *E. orariensis* had apparently resulted in *E. leptospermi* being detected within a comparatively short time of its arrival in New Zealand. When first located, *E. leptospermi* occurred only in a confined area of *L. scoparium* approximately seven miles from the nearest habitation. It is unlikely that this species became established by transfer of ornamental *L. scoparium* varieties. During the past nine years a series of surveys has shown the gradually expanding distribution of *E. leptospermi* throughout North Canterbury and more recently in the North Island in the Rangitikei Valley. *E. leptospermi* has recently been found in Waipoua Forest in Northland. The latter record may be due to artificial transfer of infected plant material or it may represent a separate establishment from an external source.

By the early 1930's, the approximate time of establishment of *E. orariensis* in New Zealand, the eastern slopes of the Southern Alps carried large and increasing stands of *L. scoparium* and to a lesser extent *L. ericoides* A. Rich. The majority of these *Leptospermum* areas had been induced by current farming methods. Thus, almost the whole of the eastern side of the main mountain chain in the South Island would provide suitable sites for the establishment of the coccid.

Along the east coast of New South Wales and the south and east coasts of Victoria, as well as in Tasmania, there are large areas of a number of *Leptospermum* species. These plants could act as suitable hosts for the coccid.

Field observations made in New Zealand and briefly reported by Hoy (1954b) showed that the main dispersion of *E. orariensis* occurred when first stage nymphs were wind-borne. It may be that nymphs could

survive long enough to be wind-borne across the Tasman Sea. There are no authenticated records of wind dispersion of coccids over such long ocean distances, a minimum of 1,200 miles being involved. Suitable winds for the transport of nymphs across the Tasman Sea do occasionally occur. The wind would need to have a medium but relatively stable velocity and the frequency of occurrence of thermal upcurrents would need to be low. Thermal upcurrents would result in the insects being carried to altitudes at which barometric pressures and low temperatures would not allow them to survive.

Insects which had been wind-borne across the Tasman Sea under north-westerly wind conditions would probably be deposited on the eastern slopes of the Southern Alps if the insects had originated in the south-eastern Australian coastal area or in Tasmania.

Presuming that this could be a possible explanation for the arrival of *E. orariensis* in New Zealand the problem of time of arrival is still outstanding. Apparently the insect has established in this country relatively recently. Even if large numbers of nymphs were annually wind-borne across the Tasman Sea there is only a slender chance of their arriving in sufficient concentration on a suitable host plant to establish since the insect cannot reproduce parthenogenically. The chances of establishment of the insect have increased over the period of the last eighty years, as farming practices have lead to a gradual increase in *Leptospermum* areas.

Mulcock (1954) identified one of the sooty mould fungi associated with *E. orariensis* in New Zealand as *Capnodium walteri* Sacc. This is an Australian species which could have entered this country in association with *E. orariensis*. On the other hand there has not been a detailed survey of the sooty mould fungi of New Zealand so that *C. walteri* may have been established here for many years in association with other coccid species.

The fact that *E. orariensis* was unknown to Australian entomologists could mean that the insect was normally held at low population levels in that country by parasites and/or predators, or as mentioned earlier, that the coccid fauna of the region was imperfectly known.

A search for *E. orariensis* in south-eastern Australia and Tasmania was undertaken by the writer during the period July to September 1956. The primary purpose of the survey was to locate the original habitat of *E. orariensis,* and if successful in this respect the writer hoped to examine the parasite-predator complex associated with the insect. Information on this point would be useful if, at some future date, the biological control of *E. orariensis* was to be attempted in New Zealand.

Leptospermum Species in S.E. Australia and Tasmania

Unlike New Zealand, Australia has a large number of species of *Leptospermum,* possibly a total of thirty. Many of the species are highly variable and classification has been difficult. Recent revisions of im-

portance include that of Wakefield (1955) for Victorian species and Curtis (1956) for Tasmanian species. To enable the recognition of species encountered in the field the writer spent some time examining herbarium material at the National Herbaria in Sydney, Melbourne, and Brisbane, and the University collections at Adelaide and Hobart. In Tasmania, as in New Zealand, the principal species is *L. scoparium*. In the south-eastern portion of the mainland the chief species is the closely related *L. juniperinum* J. Sm. On the mainland *L. scoparium* is largely confined to East Gippsland where it occurs on rocky creek and river banks and on high rocky outcrops on the Grampians (Wakefield, 1955). During this survey no specimens of *L. scoparium* other than ornamental varieties were collected on the Australian mainland. In southern Queensland *L. flavescens* J. Sm. appeared to be the principal species.

Kunzea peduncularis F.v.M. was encountered at six locations in southern New South Wales and in Victoria. This plant appeared to be identical with *Leptospermum ericoides* A. Rich. from New Zealand. This observation was confirmed by Mr N. A. Wakefield (pers. comm.) at the National Herbarium in Melbourne. *L. ericoides* is apparently not then endemic to New Zealand. This observation is interesting in view of a paper by Drake and Kehoe (1956) in which the biological control of *K. peduncularis* was discussed. This paper also includes the only published reference to the possibility that the organism responsible for the death of *Leptospermum* in New Zealand may also occur in Australia.

TABLE 1.—Collections of Leptospermum Species in South-eastern Australia and Tasmania.

Species	Fre-quency	States
L. juniperinum J. Sm.	47	N.S.W., Victoria, South Australia
L. scoparium Forst.	38	Tasmania
L. lanigerum J. Sm.	19	N.S.W., Victoria, South Australia, Tasmania
L. flavescens J. Sm.	8	Southern Queensland, N.S.W.
L. ericoides A. Rich.	6	N.S.W., Victoria
L. sericeum Labill.	5	Tasmania
L. myrtifolium Sieb. ex DC.	3	N.S.W.
L. squarrosum Gaertn.	3	N.S.W.
L. laevigatum (Soland. ex Gaert.) F.v.M.	2	South Australia, Victoria
L. scoparium ornamental vars.	2	N.S.W.
L. coriaceum (F.v.M.) Cheel	1	South Australia
L. sericatum Lindl.	1	N.S.W.
L. grandifolium J. Sm.	1	N.S.W.
L. obovatum Sweet	1	Victoria
L. attenuatum J. Sm.	1	N.S.W.
L. liversidgei R. T. Baker et H. G. Smith	1	Southern Queensland
L. humifusum A. Cunn. ex Schau.	1	Tasmania
L. nitidum Hook. F.	1	Tasmania

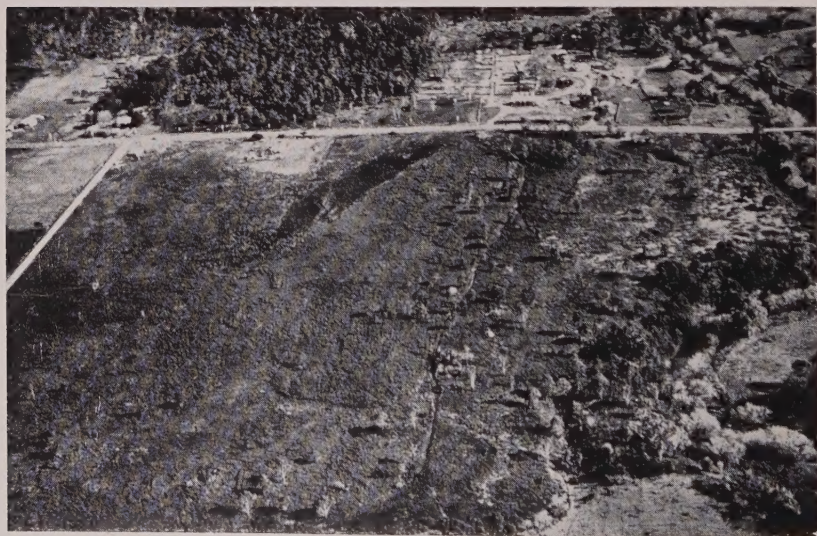FIG. 1.—*Leptospermum juniperinum* J. Sm. near Baungor, Victoria.

FIG. 2.—*Leptospermum scoparium* Forst., a typical swampy habitat near Wynyard, Tasmania.

A total of 13 different *Leptospermum* species were collected in mainland areas and 5 species in Tasmania. *Leptospermum* species from Victoria, southern New South Wales, and eastern South Australia

were identified by Mr J. Court, National Herbarium, Melbourne. Specimens from Tasmania were checked by Dr W. M. Curtis, Botany Department, University of Tasmania. Specimens from the vicinity of Sydney by Miss J. G. Garden, National Herbarium, Sydney. Specimens from southern Queensland by Mr S. L. Everist, Government Botanist, Brisbane. *L. coriaceum* from South Australia was identified by members of the staff of Waite Agricultural Institute, Adelaide. In Table 1 the species are listed in decreasing order of frequency of collection but it must be stated that collection was made on the basis of apparent coccid infestation so that the list does not accurately indicate frequency of occurrence.

The total number of apparently infested specimens was 141 of which 82 were taken from mainland areas.

L. juniperinum does not appear to be an agressive invader of improved pasture in the mainland areas as does *L. scoparium* in New Zealand. *L. scoparium* in Tasmania appeared to be chiefly confined to waste land, bush margins and others unimproved areas. Typical habitats for *L. juniperinum* and *L. scoparium* in Australia are shown in Figs 1 and 2 respectively. The observation made by Drake and Kehoe (1956) that *K. peduncularis* viz. *L. ericoides* is an agressive weed on newly developed pasture land is at variance with the position in New Zealand where this species is considered a useful shade plant in pastures. A photograph of a stand of *L. ericoides* in Victoria is shown in Fig. 3.

Fig. 3.—*Leptospermum ericoides* A. Rich., near Fernbank, Victoria.

During the survey a careful search was made for eriococcid-infected plants from genera closely allied to *Leptospermum*. The genera concerned were *Kunzea* Reichb., *Melaleuca* L., *Callistemon* R. Br. and *Baeckea* L.

AREAS SUVEYED

The areas in which detailed surveys of coccid species associated with *Leptospermum* were made are shown in Fig. 4. The bulk of the collecting both on the mainland and in Tasmania was confined to coastal areas due to the time available and the choice of suitable routes. Where possible, *Leptospermum* samples were collected in inland areas, for example, in the vicinity of Canberra 75 miles approximately, and the Grampian Mountains 90 miles from the coast. A small number of samples were collected at altitudes ranging up to 5,500 ft in the Australian Alps in the vicinity of Mt. Kosciusko. Samples were taken to an altitude of 4,000 ft on Mt. Wellington in Tasmania.

FIG. 4.—South-eastern Australia and Tasmania showing area surveyed.

Local collecting was carried out within a radius of 40 miles from Sydney, Canberra, Adelaide, and Brisbane and, where possible, along the route from Canberra, Cooma, Mt. Kosciusko, Nimmitabel, Bega, Genoa, Bairnsdale, Wilson's Promontory, Melbourne, Apollo Bay, Warrnambool, Portland, Port MacDonnell, Mt. Gambier, Casterton,

Hamilton, Hall's Gap, Beaufort, Maryborough, Ballarat, and Melbourne, also, along the southern portion of the east coast of Queensland, north from the border of New South Wales for a distance of approximately 130 miles.

· In Tasmania, local collections were made near Hobart, the southern National Park and Marrawah areas and, where possible, along the route from Hastings, Hobart, Tribunna, St. Helens, Scottsdale, Launceston, Burnie to Smithton.

The distribution of the species of *Eriococcus* on *Leptospermum* discussed in this paper is a reflection of the areas covered and gives no overall information on the distribution of coccid species on *Leptospermum* throughout Australia.

In addition to material from the above areas which were surveyed by the writer, samples of infested *Leptospermum* from the area west of Kiama, N.S.W. were collected by Mr C. E. Chadwick, Division of Science Services, N.S.W. Department of Agriculture.

Species of Coccoidea Recorded from *Leptospermum* in Australia

The species of Coccoidea previously recorded on *Leptospermum* from Australia are set out in Table 2. There are 17 species representing at least 7 families.

The family Eriococcidae is represented by one species—*Eriococcus leptospermi*. It was presumed before the commencement of the survey that this species would, at least, be the most common eriococcid encountered. All published records of *E. leptospermi* in Australia refer to the south-eastern coastal area between Sydney and Melbourne. This area had been chosen as the possible original habitat of *E. orariensis*.

Species of *Eriococcus* Collected During the Survey

All the available coccid collections in Australia were examined. Species of *Eriococcus* from *Leptospermum* were found in the collection at the Waite Agricultural Institute in Adelaide and in the Queensland Department of Agriculture's collection at Brisbane. One species in the Brisbane collection was close to *E. orariensis* but apparently distinct. No Australian specimens of either *E. leptospermi* or *E. orariensis* were found in any of the collections examined. All specimens of *Eriococcus* from *Leptospermum* in the Adelaide and Brisbane collections apparently represented new species.

TABLE 2.—List of Coccoidea Recorded from Genus *Leptospermum* in Australia.

Species	Host plant	Locality	Reference
		Family DIASPIDIDAE	
Chrysomphalus cladii (Mask.)	*Leptospermum* sp.	South Australia	Froggatt, 1915
Fiorinia fiorinae Targ.-Tozz.	*Leptospermum* sp.	Australia	Maskell 1893, Froggatt 1915
Lindingaspis rossi (Mask.)	*L. citratum* Chall. Cheel et Penfold	Beerwah, Queensland	Brimblecombe 1955
Phenacaspis angusta (Green)	*L. laevigatum*	Frankston, Victoria	Green 1904
Phenacaspis eugeniae (Mask.)	*L. laevigatum*	Australia; Victoria and N.S.W.	Maskell 1892, Fisher 1932, Froggatt 1915
Poliaspis exocarpi Mask.	*Leptospermum* sp.	Albany, West Australia	Maskell 1897
		Family ASTEROLECANIIDAE	
Amorphococcus leptospermi (Morris)	*L. laevigatum*	N.S.W.	Morrison 1927
Asterolecanium styphelioe (Mask.)	*L. juniperinum* and *L. laevigatum*	Sydney; Australia; Tasmania; Victoria	Maskell 1892, 1894, Fernald 1903, Fisher 1932, Froggatt 1915, Russell 1941
Asterolecanium victoriae Russell	*Leptospermum* sp.	Sandringham, Victoria	Russell 1941
Callococcus leptospermi (Mask.)	*L. laevigatum*	Botany, N.S.W.	Froggatt 1921a
		Family PSEUDOCOCCIDAE	
Ripersia leptospermi (Mask.)	*Leptospermum* sp.	Adelaide, S.A.; Sydney, N.S.W.	Maskell 1889, 1893
		Family MARGARODIDAE	
Icerya koebeli Mask.	*L. laevigatum*	Sydney, N.S.W.; Brisbane, Queensland	Maskell 1893

Family ERIOCOCCIDAE

Eriococcus leptospermi Mask.	*L. laevigatum* and *L. scoparium* Also recorded from *Melaleuca* sp. and *K. ambigua* (J. Sm.) Druce	Australia; Melbourne, Victoria; Sydney, N.S.W.; Healesville; Lilydale; Woolamai; Port Philip Bay; Ventnor, Victoria	Maskell 1891, Froggatt 1921a, Fisher 1932, Fraser 1933

Family COCCIDAE

Pulvinaria tecta Mask.	*L. ericoides*	Fernbank, Victoria	Drake and Kehoe 1956

Family TACHARDIIDAE

Austrotachardia melaleucae (Mask.)	*Leptospermum* sp., *L. flavescens*	Sydney, N.S.W.; Liverpool, N.S.W.	Maskell 1893, Froggatt 1921b

Genera of Uncertain Status

Eremococcus pirogallis (Mask.)	*L. flavescens*	Sydney, N.S.W.	Maskell 1894
Sphaerococcus rugosa Mask.	*Leptospermum* sp.	Mt. Barker, Western Australia	Maskell 1897

A preliminary examination of field-collected material from the Sydney area revealed that a number of *Eriococcus* species were associated with *Leptospermum* in that area and that *E. orariensis* was present on approximately one-third of the samples examined. As the survey progressed a number of other *Eriococcus* species were found. Detailed examination of specimens was not possible in the field, and all samples were accumulated at Sydney. After completion of the survey, material was fumigated to kill any live insects. All plant specimens were then brought to this laboratory where microscope slide mounts of the insects were made. An examination of these specimens confirmed that *E. orariensis* was by far the most common eriococcid on *Leptospermum* both in south-eastern Australia and in Tasmania. *E. leptospermi* had rarely been collected during the survey. *E. spiniger* Mask. was collected from *Leptospermum* for the first time and four new species of *Eriococcus* had been taken. Before discussing the distribution of these species and their effect on the host plant, it is necessary to describe the new species and to redescribe *E. leptospermi* and *E. spiniger*. These species of Maskell's would be difficult to recognize without access to the Maskell collection.

Eriococcus campbelli n.sp. (Fig. 5)

Sac of female, white, felted, occurring on stem of host plant both on the surface and in bark crevices. Infestation accompanied by heavy growth of sooty mould fungi.

Length on slide about 1·0 mm. Body shape elongate oval sometimes wider behind the mid-point of the body, penultimate and antepenultimate abdominal segments exhibit a "fish scaled" effect on the dorsum. Marginal setae of the dorsum form a prominent fringe, on abdominal segments, two setae of sub-equal length. All marginal setae of moderate length, slender with a slightly rounded tip. Remainder of dorsal setae small, relatively sparse not conforming to a definite pattern except on abdominal segments. Dorsal setae of anal lobes similar to those of the margin. Anal lobes well sclerotized, there is a small cauda which is variable in shape. Anal ring with eight setae. Tubular ducts common on dorsum, majority with a broad, shallow, more or less symmetrical cup. A few tubular ducts on anterior lateral margins of venter. Scattered small tubular ducts with bifurcate openings on dorsum, more common on anterior abdominal segments. Quinquelocular pores few in number, confined to venter. Antennae six segmented, third segment noticeably longer than any other. Posterior coxae without pores. Claw with a conspicuous tooth.
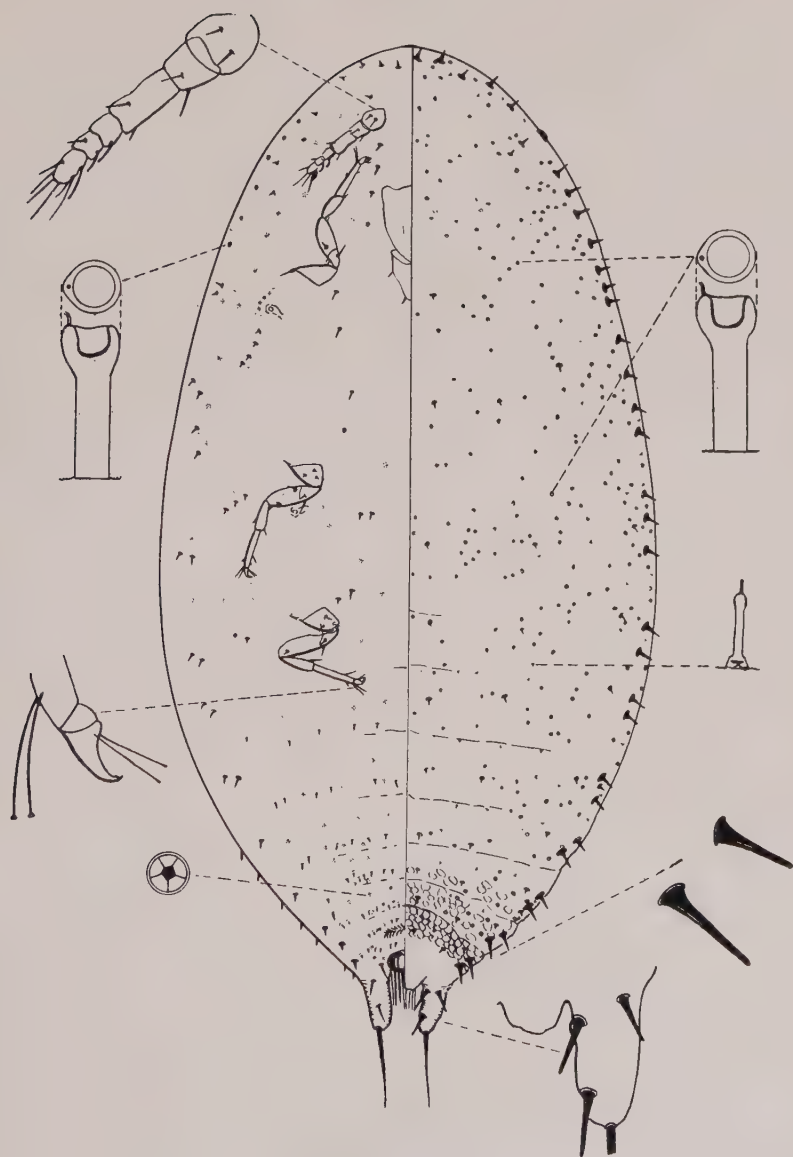
Fig. 5.—*Eriococcus campbelli* n.sp., adult female, dorsal and ventral view.

Type Locality—Peterborough, Victoria on *Leptospermum juniperinum*, collected 28/7/56.

Holotype and paratypes in collection of Entomology Division, Palmerston North, New Zealand.

Eriococcus cultellus n.sp. (Fig. 6)

Ovisac of female white, felted, occurring on the stem of the host plant more especially in crevices in the bark. Accompanied by copious growth of sooty mould fungi.

Length on slide about 1·0 mm. Body shape, broadly rounded anteriorly, tapering sharply to anal lobes. Dorsum of abdomen has a "fish scaled" pattern. Marginal setae long and slender with an expanded base and slightly rounded tip, two such setae on each margin of all abdominal segments. Other dorsal setae similar in shape but much smaller, few in number. Dorsal setae of anal lobes as for marginal setae but smaller than those of the penultimate segment. Anal lobes not strongly sclerotized, small cauda present. Eight anal ring setae. Tubular ducts numerous on dorsum with some concentration towards lateral thoracic margins. Cup of ducts, symmetrical, narrow and shallow, tube leading to gland lumen not easily distinguished. Sessile pores on venter, few in number each with a prominent, lightly sclerotized rim. Antennae 6 segmented. No pores on posterior coxae. Claw with a definite tooth.

Type Locality—St. Ives, N.S.W. on *Leptospermum squarrosum,* collected 5/7/56.

Holotype and paratypes in collection of Entomology Division, Palmerston North, New Zealand.

Eriococcus gibbus n.sp. (Fig. 7)

The female of this species occupies crevices in the bark on the larger stems of the host plant. There is no indication of a true ovisac, females being surrounded by small quantities of white wax. Length on slide about 1·5 mm. Body shape very elongate and slender, in life the insect has a curious hump-backed appearance. Margins of dorsum almost devoid of setae, remainder of dorsum beset with large numbers of short setae, the anterior dorsal setae tapering to a slightly rounded tip, posterior dorsal setae almost parallel sided with a blunt tip. Setae on the dorsal surface of anal lobes 4 in number similar to posterior dorsal setae. Anal lobes lightly sclerotized. Anal ring with 8 setae. Tubular ducts, relatively few in number with broad shallow cups. Numerous smaller tubular ducts on dorsum, these ducts with bifurcate openings. Sessile pores present in large numbers both on the venter and on the dorsal margins. Antennae 7 segmented. Posterior coxae with a few pores. Claw with a definite tooth.

Type Locality—Wynyard, Tasmania, on *Leptospermum scoparium* collected 15/8/56.

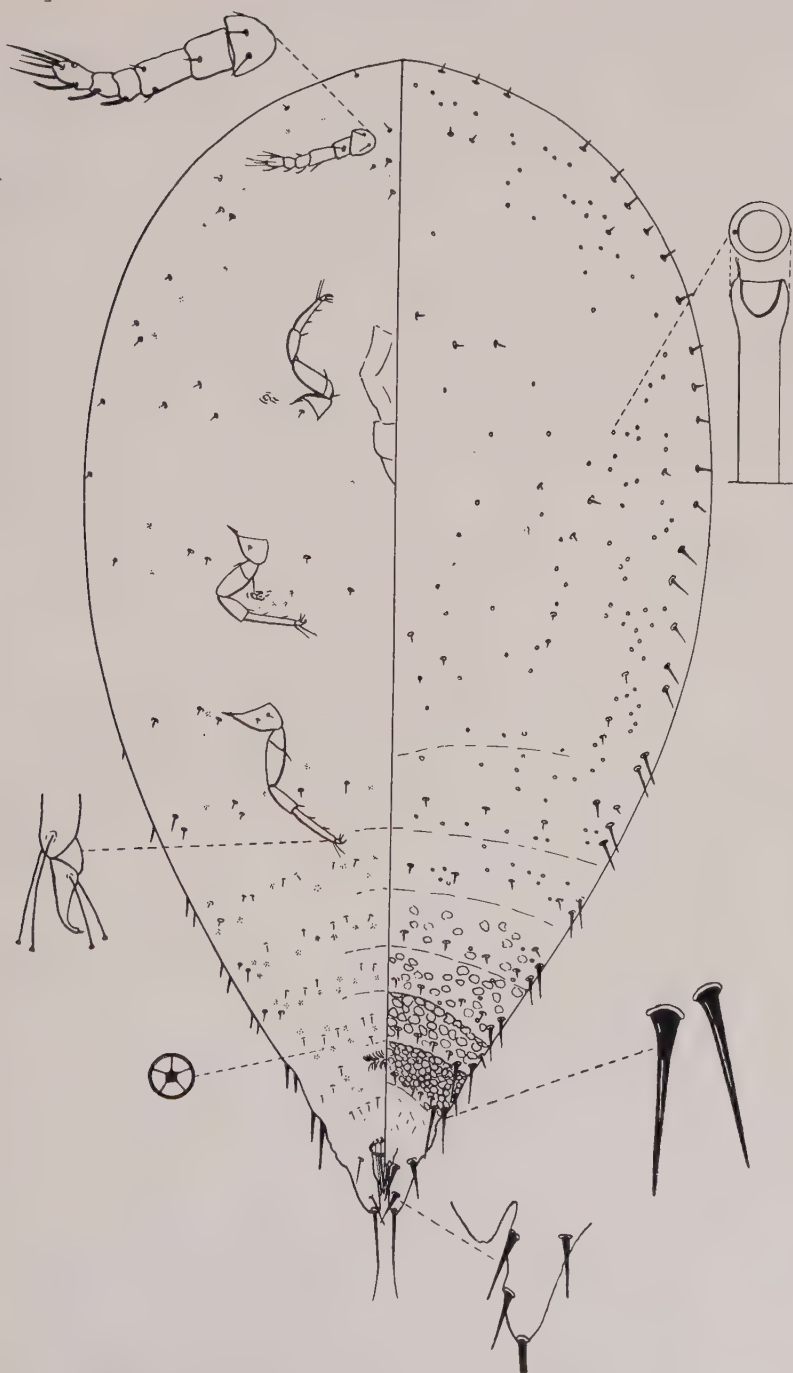Holotype and paratypes in collection of Entomology Division, Palmerston North, New Zealand.

Fig. 6.—*Eriococcus cultellus* n.sp., adult female, dorsal and ventral view.
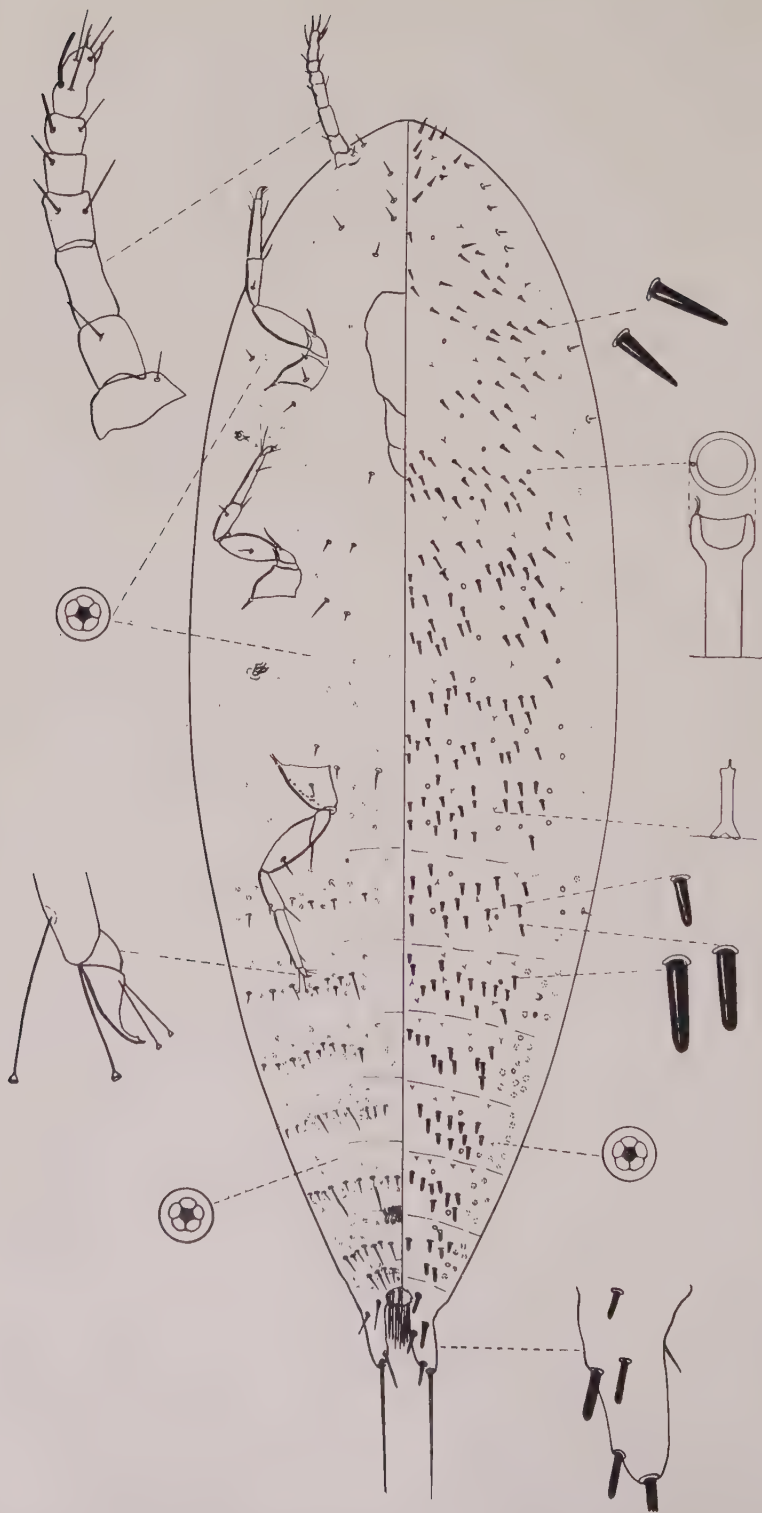
Fig. 7.—*Eriococcus gibbus* n.sp., adult female, dorsal and ventral view.

Fig. 8.—*Eriococcus leptospermi* Maskell, adult female, dorsal and ventral view.

Eriococcus leptospermi Maskell (1891) (Fig. 8)

Specimens of *E. leptospermi* in the Maskell collection are unsuitable for illustration. The specimen figured is from *L. scoparium*, Waipoua Forest, New Zealand. The appearance of the adult female on the host plants is as figured by Maskell. In contrast to the majority of *Eriococcus* species occurring on *Leptospermum*, the female of *E. leptospermi* is usually found onl the surface of the bark on the stem rather than in

bark crevices. Length of female on slide slightly less than 0·9 mm.
Form, rounded anteriorly tapering to the anal lobes. Dorsum beset with
moderate length, broad based setae, those of abdominal segments ar-
ranged in transverse rows. Setae on dorsal inner margin of anal lobes
longer and more slender than dorsal body setae. Anal lobes moderately
sclerotized. Anal ring with 8 setae. Tubular ducts of dorsum with a
deep symmetrical cup. Bifurcate tubular ducts common on dorsum.
Sessile pores on venter almost all quinquelocular, an occasional trilocular
pore occurs on the anterior ventral region. Antennae 6 segmented. A
few pores on the posterior coxae. Tarsal claw with a small tooth.

Type Locality—Australia, district not stated, on *Leptospermum* sp.

Material examined included 5 slides of *E. leptospermi* from the
Maskell collection labelled: *Eriococcus leptospermi*—adult female, 1890
W.M.M.; abdomen of adult female, Aug. 1890 W.M.M.; 2nd stage
female and larvae, Aug. 1890 W.M.M.; larvae (Australia) 1891
W.M.M.; male (Australia) 1891 W.M.M.

Plesiotype in collection of Entomology Division, Palmerston North,
New Zealand.

Eriococcus milleri n.sp. (Fig. 9)

Sac of female, white, felted, prominent, occurring mainly on the
undersides of the leaves of the host plant. Length of adult female, on
the slide, about 1·2 mm. Body shape oval, tapering to anal lobes. No
definite marginal fringe of setae, dorsum beset with setae varying in
size but all relatively broad in base tapering to a slightly rounded tip,
setae not arranged in a definite pattern. Anal lobes lightly sclerotized
with a slightly sinuous inner margin. Anal ring with 8 setae. A small
cauda is present. Tubular ducts on dorsum few in number, each with
a deep symmetrical cup. Pores on venter mostly quinquelocular but an
occasional quadrilocular pore can be found. Antennae 7 segmented.
Posterior coxae without pores. Markedly recurved claw with a distinct
tooth.

Type Locality—Mt. Wellington, Tasmania on *Leptospermum lani-
gerum,* collected on 7/8/56.

Holotype and paratypes in collection of Entomology Division, Palm-
erston North, New Zealand.

Eriococcus orariensis Hoy (1954b) (Fig. 10A, B)

As mentioned earlier in this paper, specimens of a species close to
E. orariensis were found in the collection of the Department of Agri-
culture, Brisbane. The most noticeable feature of this insect was the
row of peg-shaped setae across the dorsum of the penultimate ab-
dominal segment (Fig. 10A). In all other respects it appeared identical
with *E. orariensis*. The arrangement of setae on the dorsum of the
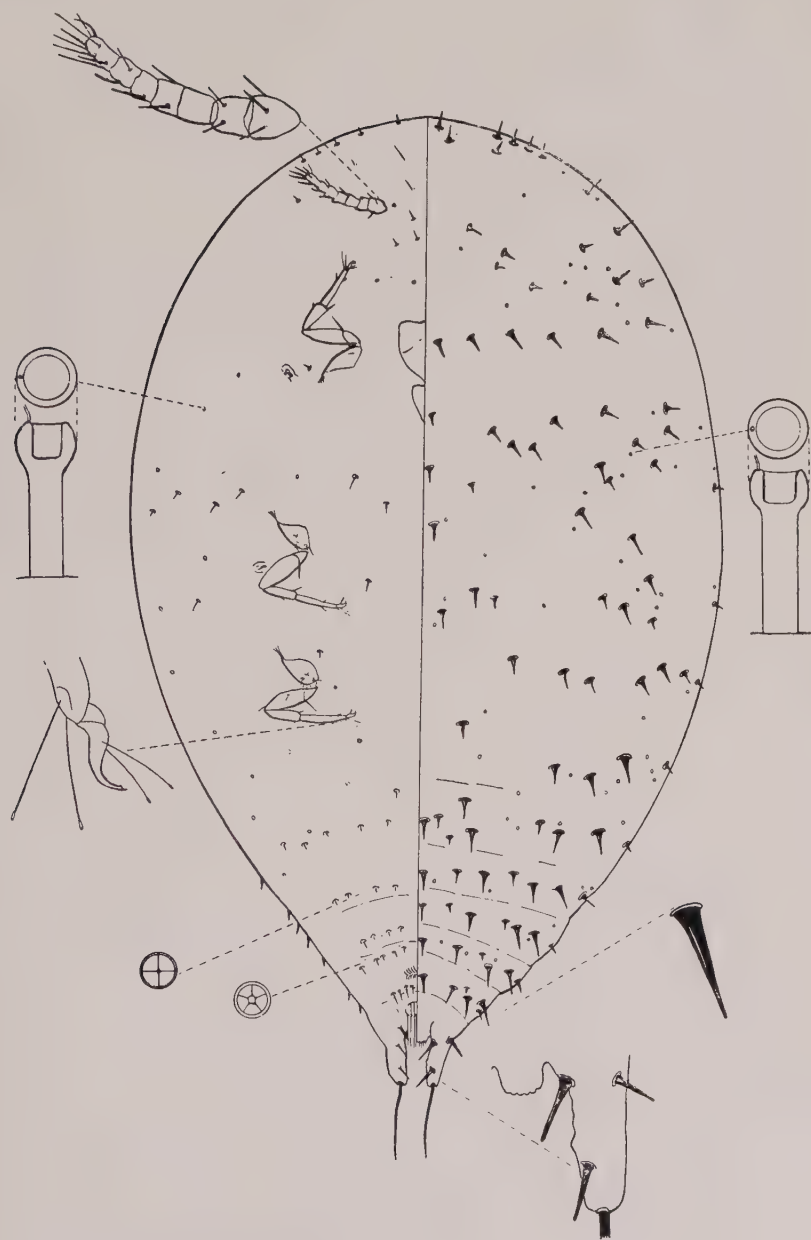penultimate segment of a paratype female of *E. orariensis* is shown
in Fig. 10B.

Fig. 9.—*Eriococcus milleri* n.sp., adult female, dorsal and ventral view.

With the co-operation of Mr A. R. Brimblecombe, the writer was able to obtain coccids from the original plant of *L. flavescens* even though the slides in Brisbane collection had been made some twenty years previously. Specimens of the same insect were also obtained from
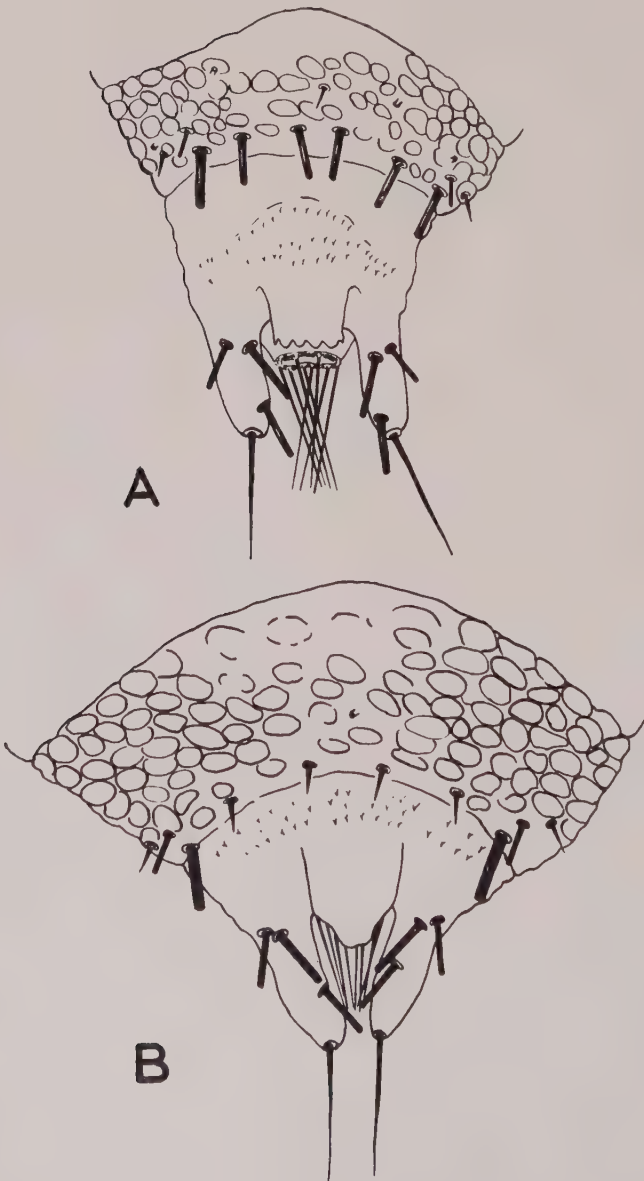
FIG. 10A.—*Eriococcus orariensis* Hoy, dorsum of abdomen, extreme variation, Queensland form.

FIG 10B.—*Eriococcus orariensis*, dorsum of abdomen, paratype specimen.

L. liversidgei at Colundra. A series of slides were prepared, and when examined, they revealed that the form represented in Fig. 10A was an extreme at one end of the range and that the range extended to include typical examples of *E. orariensis*. It would appear that the variation in Queensland specimens of *E. orariensis* is infrasubspecific.

All other specimens of *E. orariensis* in Australia conform to the characters of the type series.

Type Locality—Maronan, Canterbury, New Zealand on *Leptospermum scoparium,* collected on 13/3/50.

Holotype and paratypes in collection of Entomology Division, Palmerston North, New Zealand.

Eriococcus spiniger Mask. (1896) (Fig. 11)

This species was described by Maskell from material taken at Oatley near Sydney on an undetermined species of *Eucalyptus*. As far as can be ascertained the species has not been recovered between 1895 and the time of this survey. An examination of material labelled *E. spiniger* in the Maskell collection showed that Maskell had been mistaken in stating that the anal ring had 8 setae. One female specimen in the collection has 6 anal ring setae, the other available specimen is too distorted to allow a count of anal ring setae.

Specimens taken from *L. coriaceum* at Monarto South, South Australia, agree closely with Maskell's material except that each abdominal segment in the female carries 4 blunt setae on each margin, Maskell's specimens have 5 setae. The following description and the accompanying Fig. 11 are based on specimens from Monarto.

Sac of the female grey-white, felted, occurring on underleaf surface of host plant rarely on upper leaf surface. Length of adult female, on slide, about 1·2 mm. Body shape elongate oval. Dorsum apparently devoid of setae except for a prominent marginal fringe of stout blunt tipped setae, those of the abdominal segments occurring 4 to each segmental margin. Setae on dorsum of anal lobes, small and acutely tapering. Anal lobes, well sclerotized, nearly parallel-sided with a series of strongly sclerotized teeth on the inner margins, a small cauda is present. Anal ring setae 6 in number. Tubular ducts, very numerous on dorsum and on ventral margins. Cup of duct relatively deep and slightly asymmetrical. Pores on venter, quinquelocular with small lens shaped terminations to the loculi. Antennae 6 segmented, third segment not longer than terminal segment. Tarsal claw with a small tooth. Posterior coxae with a small number of pores.

Type Locality—Oatley, N.S.W. on *Eucalyptus* sp., collected 1895.

Material examined included 4 slides labelled *Eriococcus spiniger*—adult female 1895—W.M.M. (2 slides), antennae of female 1895—W.M.M., larva 1895 W.M.M.

Plesiotype from *Leptospermum coriaceum,* Monarto South, South Australia, collected 23/8/56 by Miss H. M. Brookes. In collection of Entomology Division, Palmerston North, New Zealand.
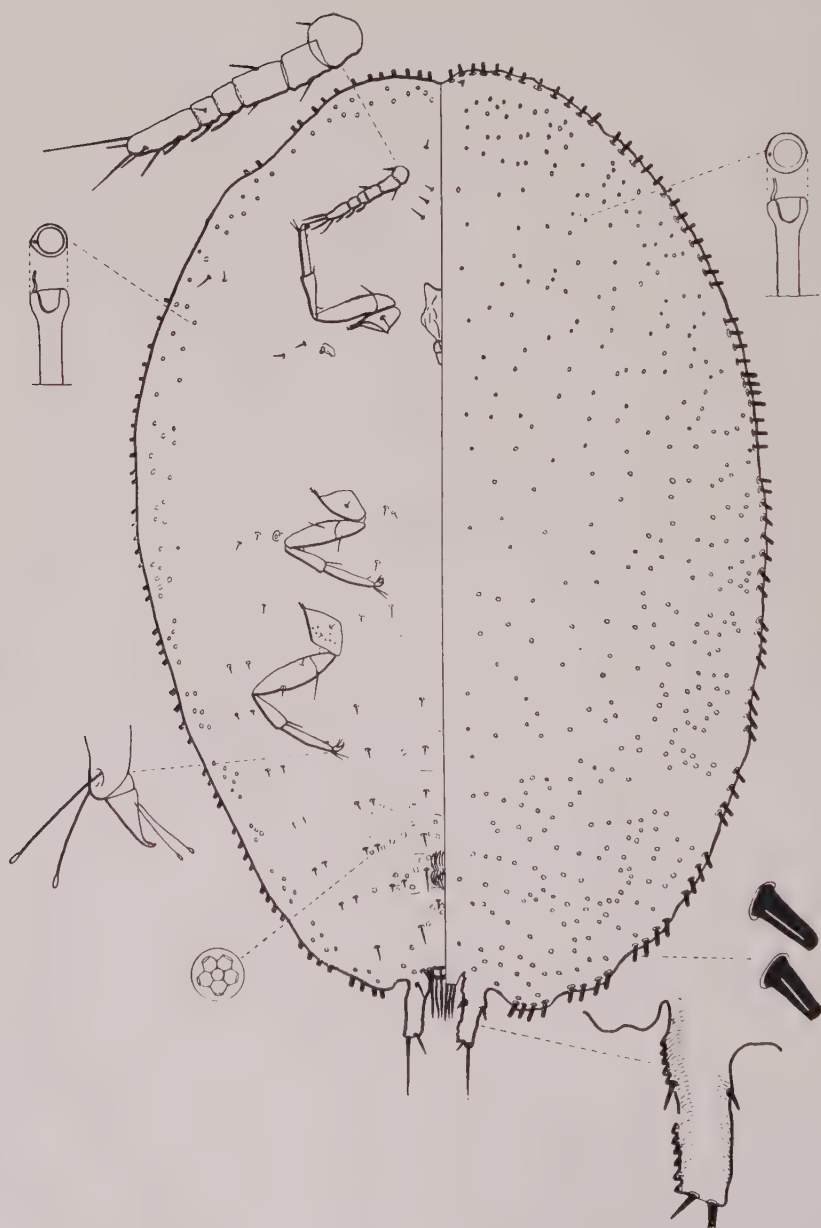
Fig. 11.—*Eriococcus spiniger* Maskell, adult female, dorsal and ventral view.

Key to Species of *Eriococcus* Known to Occur on
Leptospermum spp. in Australia

1.	Antennae 6—segmented	2
	Antennae 7—segmented	6
2 (1).	Cup of tubular ducts markedly asymmetrical	***orariensis***
	Cup of tubular ducts more or less symmetrical	3
3 (2).	Mesal margins of anal lobes beset with teeth	***spiniger***
	Mesal margins of anal lobes without teeth	4
4 (3).	Dorsal differentiated setae, at least in part, equalling marginal setae, these broadly based and relatively short	***leptospermi***
	Dorsal differentiated setae markedly smaller than marginal setae	5
5 (4).	Marginal setae of penultimate abdominal segment almost as long as anal lobes	***cultellus***
	Marginal setae of penultimate abdominal segment much shorter than anal lobes	***campbelli***
6 (1).	Anal lobes with 3 dorsal setae	***gibbus***
	Anal lobes with 4 dorsal setae	***milleri***

Paratype material of all new species will be deposited in the collection of the Entomology Division, Commonwealth Scientific and Industrial Research Organization, Canberra.

HOST RELATIONSHIPS OF SPECIES OF *Eriococcus* ON AUSTRALIAN
Leptospermum spp.

The relationship between the various species of *Eriococcus* and the host species of *Leptospermum* is summarized in Table 3.
One hundred and forty-one apparently infested specimens of *Leptospermum,* representing 17 species, were brought back to New Zealand. Detailed examination in the laboratory revealed the presence of *Eriococcus* spp. in 122 cases, 74 records from the mainland and 48 records from Tasmania. Other coccid species were recorded on 50 occasions and no coccids were recovered from 12 plant specimens. The difference in numbers is caused by multiple infections in a number of cases. Species of *Eriococcus* were associated with 15 of the 17 *Leptospermum* species collected in Australia.

Eriococcus orariensis
    This species was by far the most common eriococcid collected during the survey with 76 records out of a total of 122. *E. orariensis* was widely distributed geographically as shown in the map in Fig. 12. This map shows *E. orariensis* to be present at both western and northern limits of the survey area. It would be reasonable to presume that the species is more widely distributed than is shown on the map.

TABLE 3.—Host Records for Eriococcus Species on the Genus *Leptospermum* in Australia.

| *Leptospermum* spp.	Eriococcus species							Total records per host species
	orariensis	*campbelli*	*leptospermi*	*cultellus*	*gibbus*	*spiniger*	*milleri*	
MAINLAND								
juniperium	31	10	3	—	—	—	—	44
lanigerum	3	1	1	—	—	—	—	5
Ornamental *scoparium*	2	1	—	—	—	—	—	3
flavescens	1	3	4	1	—	—	—	9
ericoides	1	1	1	—	—	—	—	3
liversidgei	1	1	—	—	—	—	—	2
squarrosum	—	1	—	2	—	—	—	3
obovatum	—	—	—	1	—	—	—	1
coriaceum	—	—	—	—	1	—	—	1
laevigatum	—	—	1	—	—	—	—	1
sericatum	—	1	—	—	—	—	—	1
myrtifolium	—	—	—	—	—	1	—	1
attenuatum	—	—	—	—	—	—	—	—
grandifolium	—	—	—	—	—	—	—	—
TASMANIA								
scoparium	32	2	1	—	—	—	1	36
lanigerum	5	3	—	—	2	—	—	10
nitidum	—	1	—	—	—	—	—	1
sericeum	—	1	—	—	—	—	—	1
humifusum	—	—	—	—	—	—	—	—
Total records per insect sp.	76	26	11	4	3	1	1	
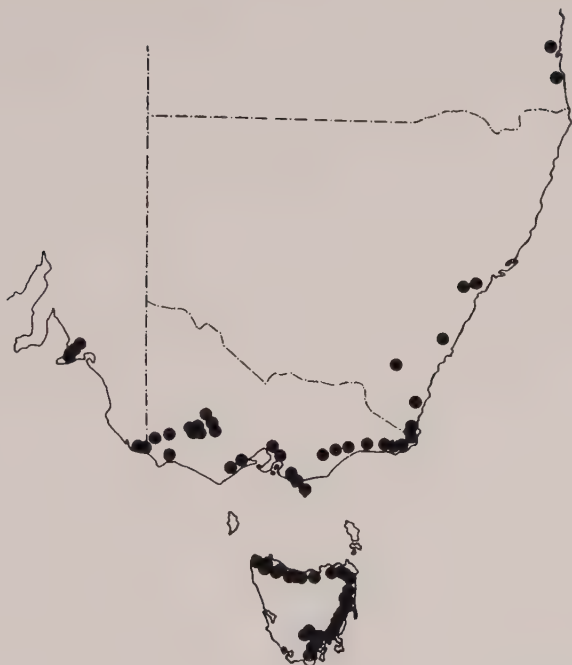
FIG. 12.—Distribution of *E. orariensis* in South-eastern Australia and Tasmania.

E. orariensis was associted with six *Leptospermum* species namely—
L. scoparium, L. juniperinum, L. lanigerum, L. ericoides, L. flavescens,
and *L. liversidgei*. Only the first three plant species were infested on
more than two occasions in the collected material. It was particularly
difficult to assess the effect of *E. orariensis* on the host plant under
Australian conditions. The majority of the *Leptospermum* areas had
been subject to fire. In a few areas, isolated plants of both *L. juni-
perinum* and *L. scoparium* appeared to have been insect killed. As far
as could be ascertained in the field, the population levels of *E. orariensis*
were much lower than those experienced in New Zealand. This factor
is presumably the cause of the very low mortality level in *Leptospermum*
in Australia.

Plants from a number of genera closely related to *Leptospermum*
were examined for the presence of *E. orariensis*. Specimens of *Kunzea,
Melaleuca, Callistemon,* and *Baeckea* were not infested by *E. orariensis*.
This insect has not been recorded from any plant host outside the
genus *Leptospermum*.

Eriococcus campbelli

This new species was the second most abundant *Eriococcus* with 26
records. The distribution of this coccid is shown in Fig. 13. *E. camp-
belli* was associated with a wider range of *Leptospermum* species than
E. orariensis. During the survey it was recorded from 10 of the 17
Leptospermum spp.

Fig. 13.—Distribution of *E. campbelli* in South-eastern Australia and Tasmania.

Fig. 14.—Stand of *Leptospermum scoparium* and *L. lanigerum* partly killed by *E. campbelli*, Huonville, Tasmania.

If the writer had been faced with the selection of a biological control agent for use against *L. scoparium* in New Zealand, he would have chosen *E. campbelli*. Although this insect was less frequently encountered than *E. orariensis*, it was more frequently involved with the death of the host plant whether that plant was *L. scoparium*, *L. junipérinum*, or *L. lanigerum*. Figure 14 shows a dying stand of *L. scoparium* and *L. lanigerum* attacked by *E. campbelli*.

Eriococcus leptospermi

The relatively infrequent occurrence of this species (Fig. 15) is rather puzzling. All existing records of *Eriococcus* species on *Leptospermum* in Australia refer to this species. Froggatt (1921a) states that it probably has a wide range along the eastern and southern coasts. Fisher (1932) makes numerous references to *E. leptospermi* in the southern coastal area of Victoria. Either the majority of specimens referred to this species in the past were incorrectly identified or the species is now much less abundant in coastal areas than formerly, the writer covering the coastal area to which the majority of the records refer.

Fig. 15.—Distribution of *E. leptospermi* in South-eastern Australia and Tasmania.

Other Species of *Eriococcus*

The distribution of the remaining four species is shown in Fig. 16. *E. cultellus* was taken on 4 occasions, 3 in the vicinity of Sydney and 1 near Bairnsdale in Victoria. *E. gibbus* was taken on both sides of Bass Strait. *E. spiniger* and *E. milleri* were each collected on 1 occasion. It was not possible to assess the effect of the last 5 species on the host plants as the insects were were not encountered in high concentrations.

● *E. cultellus*

▼ *E. gibbus*

■ *E. milleri*

▲ *E. spiniger*

Fig. 16.—Distribution of other *Eriococcus* species on *Leptospermum* in South-eastern Australia and Tasmania.

Natural Enemies of *Eriococcus* spp. on *Leptospermum*
in Australia

The winter period is an unsuitable time to assess either parasitism
or predation on Coccoidea, but a careful watch was kept in the field
for evidence of natural control. The situation was further complicated
by the limited facilities available in the field for rearing parasites and
the difficulty of separating the various species of *Eriococcus* without
making slide mounts. Several parasite species were reared from in-
fested material collected in western coastal Victoria. At the time it was
thought that these insects were parasitizing *E. orariensis* but when
slide mounts were made, after return to New Zealand, the host insect
proved to be the new species, *E. campbelli*. Dr E. Riek of the Division
of Entomology, C.S.I.R.O., kindly determined the genera of these
parasites as follows:

Aphelininae	1.	*Aphytis* sp.
	2.	A new genus or a Giraultian near *Coccophagus* sp.
Pteromalidae	1.	One species undet.
Encyrtidae	1.	*Aphidencyrtus* sp. (possibly a hyperparasite)

A further species was reared but could not be determined from the
available material.

Slide mounts of *Eriococcus* species from all specimens collected were
searched for the presence or absence of parasites. The absence of
parasites on a slide does not preclude the possibility of parasitism in a
locality, but the presence of parasites in the relatively small amount
of insect material mounted could be an indication of a high level of
parasitism in the field. In addition, each infested plant specimen was
individually wrapped and the debris from each package was searched
for any parasites which may have reared out before the specimens
were fumigated at Sydney.

Using these methods, parasites of *E. orariensis* were found from 5
localities on the mainland and from 9 areas in Tasmania. Parasites of
the other *Eriococcus* species were taken from 10 localities on the main-
land and 3 in Tasmania. The majority of the parasites were in either
the larval or pupal stages making identification almost impossible but
most appear to belong to superfamily Chalcidoidea.

On the basis of parasitism and the availability of insect host material
in the field, a number of locations were tentatively selected should
future work on the biological control of *E. orariensis* be considered.
These areas are shown in Fig. 17. The areas marked A, B, D, and E
conform to the above criteria but in all cases the task of collecting
specifically from *E. orariensis* would be complicated by the presence
of other species of *Eriococcus* on *Leptospermum*. Area C has been
included as it appears to be one of the few places included in the
survey where *E. orariensis* is the only eriococcid species on *Lepto-
spermum*.

Predation by coccinellid larvae and by small, coccid eating lepidopterous larvae was common throughout the areas surveyed. No material could be reared so the species involved have not been determined.

Fig. 17.—Areas suitable for any future work on parasites of *E. orariensis*.

Discussion

All the available evidence tends to support the conclusion that *E. orariensis* was windborne across the Tasman Sea and landed on a suitable host plant in sufficient concentration to establish. There is little likelihood of proof of this assertion, but the hypothesis served its major function in allowing the discovery of the original habitat of *E. orariensis*. This insect is the most widely distributed and most frequently occurring coccid species associated with *Leptospermum* in south-eastern Australia and Tasmania. The relatively large complex of *Eriococcus* species associated with *Leptospermum* in Australia was unexpected. Prior to the survey the writer presumed that *E. leptospermi* was likely to be the most common species encountered and that the general level of ericoccid infestation on *Leptospermum* was low. This assumption was based on two factors, firstly, all published records refer to *E. leptospermi* and secondly, detection of eriococcid infestations on *Leptospermum* is simplified by the presence of copious deposits of "sooty mould" fungi.

There would appear to be a large number of undiscovered species in the genus *Eriococcus* in Australia. The same remark would also apply to other genera. Excluding *E. leptospermi* a total of 16 coccid species have been recorded from *Leptospermum* in Australia. During the current survey the following previously known species were collected: *Asterolecanium victoriae, Amorphococcus leptospermi, Callococcus leptospermi,* and *Eremococcus pirogallis.* Thus, of a total of 17 recorded species, 5 were collected. This paper adds two new records for described species of *Eriococcus* and lists 4 new species in that genus. In addition 8 apparently new forms belonging to 4 families of Coccoidea were collected. Consideration of these species will be left for another paper.

It was extremely difficult to assess the effect of *E. orariensis* on its host plant under Australian conditions but, in general, the insect did not appear to be responsible for the death of many plants. Although no quantitative data can be presented, the population levels of *E. orariensis* were considerably lower than those found in New Zealand. The major factor responsible for this difference is probably the presence of a well developed predator-parasite complex in Australia. An unknown factor is the possible acquired immunity or resistance to attack of host species of *Leptospermum,* particularly *L. juniperinum* and *L. scoparium.* In order to obtain some information on this point, plants of both species are being raised in New Zealand in quarantine from seed collected on a regional basis in Australia. When these plants are large enough they will be artificially infested with known populations of first stage nymphs of *E. orariensis.* The ability of the Australian plants to withstand attack by *E. orariensis* in comparison with New Zealand plants can then be assessed in the absence of parasitism and predation on the insect.

Where infested stands of *Leptospermum* were adjacent to dusty roads in Australia there was a marked decline in population levels of both *E. orariensis* and *E. campbelli* along a line at right-angles to the roadway. Higher populations occurred close to the road and a lower and more uniform level was encountered at a distance of 30 to 40 yards from the road edge. This difference may be due to the presence of road dust reducing the effectiveness of parasites and predators near the road margins. DeBach (1951) in commenting on a similar situation with Californian Red Scale (*Aonidiella aurantii* (Mask.)) noted a lack of confirmative population studies. The parasite-predator complex associated with either *E. orariensis* or *E. campbelli* would make these insects ideal subjects for such a study.

Drake and Kehoe (1956) in discussing *Leptospermum ericoides* under the name of *Kunzea peduncularis* note that it is an aggressive invader of improved pasture, while *L. scoparium* (?*L. juniperinum*) is of little consequence in this respect. It is possible that this apparent reversal of roles, by New Zealand standards, is associated with the effect of *E. orariensis* on its host. If this is the case some increase in *L. ericoides* in New Zealand can be expected following the removal of *L. scoparium* by the scale insect.

During the 3 months spent in the field in Australia, there was little opportunity for a detailed study of the parasite complex associated with *E. orariensis*. Five sites for any future work on parasites were selected. If it is necessary, at any time, to consider the introduction into New Zealand of biological agents to control *E. orariensis*, a lengthy period of field study would be required. The parasite complex undoubtedly contains hyperparasites and a study of these would involve the setting up of a field laboratory.

One of the most interesting points to emerge from this survey relates to the apparent relative efficiency of *E. orariensis* and *E. campbelli* in killing their host plants in their original habitat. It may be that *E. campbelli* would be more efficient than *E. orariensis* has been in this country. On the other hand, the spectacular control of *L. scoparium* by *E. orariensis* shows that once removed from its parasite-predator complex it is an efficient biological control agent. This observation leaves out of consideration for the moment the possibility that our New Zealand *L. scoparium* may be less resistant than the Australian; it may have to be modified when we have results of the tests mentioned above concerning the comparative ability of Australian and New Zealand plants of the species to withstand infestation by *E. orariensis*. Recognition of these factors of biological control and relative resistance is important in the selection of biological agents for use against weed plants.

Mr J. Willis and Mr J. Court of the National Herbarium, Melbourne
and Mr N .A. Wakefield; in South Australia. Mr D. C. Swan, Mr K.
Doull and Miss H. M. Brookes of the Department of Entomology,
Waite Agricultural Research Institute; in Tasmania, Mr L. W. Miller
of the Entomolgy Division, Department of Agriculture, Dr W. M.
Curtis of the Botany Department, University of Tasmania and those
officers of the Forestry Commission who provided transport and assist-
ance in the field surveys.

References

Brimblecombe, A. R., 1955: Studies of the Coccoidea 3. The Genera *Chentraspis,
Clavaspis, Lindingaspis,* and *Morganella* in Queensland. *Qld. J.
agric. Sci.* 12 : 39-56.

Curtis, W. M., 1956: "Students Flora of Tasmania". Part 1. pp. 195-8. Govt.
Printer, Hobart.

De Bach, P., 1951: The Necessity for an Ecological Approach to Pest Control
on Citrus in California. *J. econ. Ent.* 44 : 443-7.

Drake, F. R.; Kehoe, J. K., 1956: "Manuka" Control in East Gippsland. *Vict. J.
Agric.* 54 : 49-52, 60.

Fernald, M. E., 1903: "A Catalogue of the Coccidae of the World". Press of
Carpenter and Morehouse, Amherst, Mass., U.S.A., 360 pp.

Fisher, E. E., 1932: The "Sooty Moulds" of Some Australian Plants. *Proc. roy.
Soc. Vict.* 45 : 171-202.

Fraser, L., 1933: An Investigation of the Sooty Moulds of New South Wales. i.
Proc. Linn. Soc. N.S.W. 58 : 375-95.

Froggatt, W. W., 1915: A Descriptive Catalogue of the Scale Insects ("Coccidae")
of Australia. Part 1. *N.S.W. Dept. agric. Sci. Bull.* 14 : 64 pp.

———, 1921a: A Descriptive Catalogue of the Scale Insects ("Coccidae") of
Australia. Part II. *Ibid.* 18 : 159 pp.

———, 1921b: A Descriptive Catalogue of the Scale Insects ("Coccidae") of
Australia. Part III. *Ibid.* 19 : 43 pp.

Green, E. E., 1904: Descriptions of some New Victorian Coccidae. *Vict. Nat.* 21 :
65-9.

Hoy, J. M., 1953: First Record of the Occurrence of *Eriococcus leptospermi*
Mask. in New Zealand. *N.Z. Ent.* 1 : 3 : 1.

———, 1954a: Scale Insects Associated with Manuka Species in New Zealand.
N.Z. J. Agric. 89 : 601-4.

———, 1954b: A New Species of *Eriococcus* Targ. (Hemiptera, Coccidae)
Attacking *Leptospermum* in New Zealand. *Trans. roy. Soc. N.Z.*
82 : 465-74.

Maskell, W. M., 1889: On Some New South Australian Coccidae. *Trans. roy.
Soc. S. Aust.* 11 (1888) : 101-11.

———, 1891: Further Coccid Notes: With Descriptions of New Species from
New Zealand, Australia, and Fiji. *Trans. and Proc. N.Z. Inst.* 23
(1890) : 1-36.

———, 1892: Further Coccid Notes: With Descriptions of New Species
and Remarks on Coccidae from New Zealand, Australia, and
elsewhere. *Ibid.* 24 (1891) : 1-64.

———, 1893: Further Coccid Notes: With Descriptions of New Species from
Australia, India. Sandwich Islands, Demerara, and South Pacific.
Ibid. 25 (1892) : 201-52.

————, 1894: Further Coccid Notes with Descriptions of Several New Species and Discussion of Various Points of Interest. *Ibid.* *26* (1893) : 65-105.

————, 1896: Further Coccid Notes with Descriptions of New Species and Discussions of Questions of Interest. *Ibid.* *28* (1895) : 380-411.

————, 1897: Further Coccid Notes: With Descriptions of New Species and Discussions of Points of Interest. *Ibid.* *29* (1896) : 293-311.

MORRISON, H.; MORRISON, E., 1927: The Maskell Species of Scale Insects of the Subfamily Asterolecaniinae. *Proc. U.S. Nat. Mus.* *71* : *17* : 1-42.

MULCOCK, A. P., 1954: A Disease of Manuka *Leptospermum scoparium* Forst. *Trans. roy. Soc. N.Z.* *82* : 115-18.

RUSSELL, L. M., 1941: A Classification of the Scale Insect Genus *Asterolecanium.* *U.S.D.A. Misc. Pub. 424.* 319 pp.

WAKEFIELD, N. A., 1955: Flora of Victoria: New Species and Other Additions—2. *Vict. Nat.* *72* : 43-7.

CONTRIBUTIONS TO THE QUATERNARY HISTORY OF THE NEW ZEALAND FLORA

3. POLLEN ANALYSIS OF A PEAT PROFILE FROM ANTIPODES ISLAND

By N. T. MOAR, Botany Division, Department of Scientific and Industrial Research, Christchurch

Summary

Pollen analysis of a shallow profile 51 in. (127 cm) deep, from Antipodes Island some 400 miles (640 km) south-east of the South Island, New Zealand, shows that there have been no significant changes in vegetation on the island since peat-formation was initiated, although the higher frequencies of pollen of *Anisotome* and *Pleurophyllum* at the base of the profile suggest that wetter soil conditions existed at that time. Smooth-walled, monolete fern spores were found to be present in greater numbers than any other spore or pollen type. The most abundant angiosperm pollen recorded was that of the Gramineae. The low percentages of pollen of *Podocarpus* and *Nothofagus* suggest that these have been carried to the island by wind from the South Island of New Zealand.

INTRODUCTION

Antipodes Island, longitude 178° 43′ E and latitude 49° 41′ S, is a small, cliffed island of volcanic origin some 5 miles long and 3 miles wide lying about 400 miles (640 km) south-east of the southern coast of the South Island of New Zealand. The island rises steeply from the sea to an undulating plateau which is dissected by deep, narrow gullies. The plateau rises in long sweeps to Mt. Galloway (1,320 ft, 403 m), its highest point (Speight, 1909; Fig. 1). The steep slopes rising to the plateau are interrupted at intervals by cliffs ranging in height from 80 ft (24 m) to more than 400 ft (122 m).
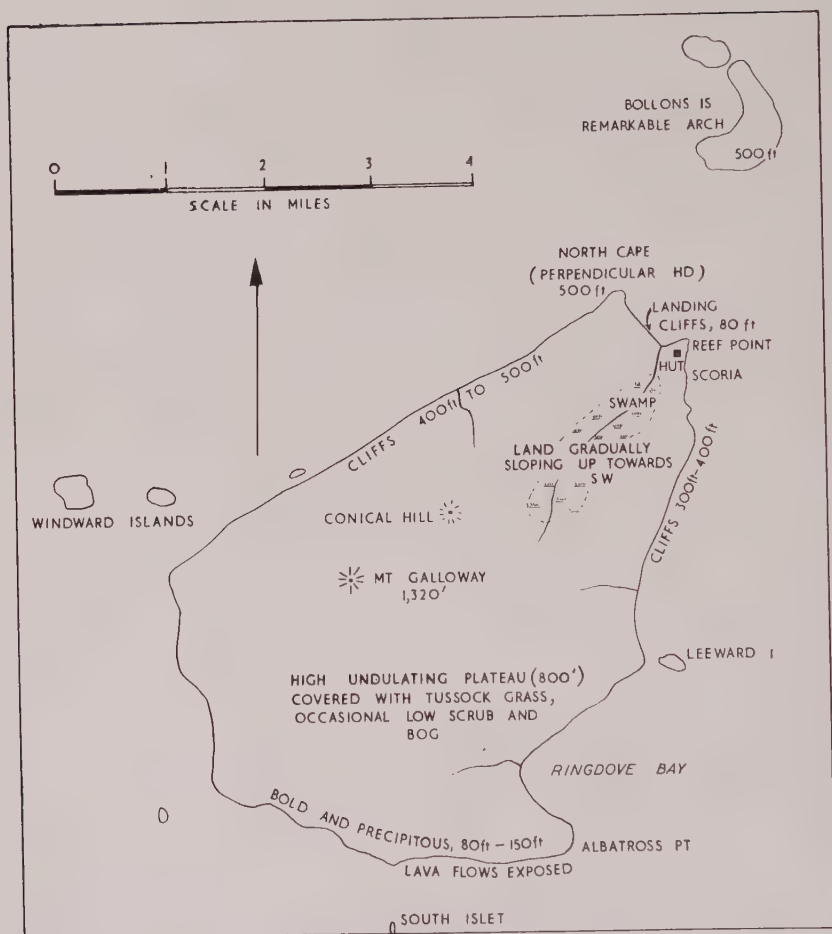
FIG. 1.—Antipodes Island (redrawn from "Subantarctic Islands of New Zealand." Vol. 2, p. 741).

Meteorological records are lacking, but Falla (1948) states that the appearance of the vegetation suggests "abundant rainfall, high humidity, and frequent wind."

The vegetation of the peat-covered plateau is dominated by *Poa litorosa* Cheesem. and *Polystichum vestitum* (Swartz) Presl. *Anisotome antipoda* Hook. f. and *Hypolepis millefolia* Hook. are important components of this community. In shallow depressions there are wet boggy areas in which *Poa litorosa* is commonly absent, and in which *Anisotome antipoda* is abundant; in swamps, which are often extensive, *Poa*

litorosa and *Polystichum vestitum* are abundant. Stunted shrubs of *Coprosma ciliata* Hook. f. and *C. cuneata* Hook. f. grow in sheltered valleys (Cockayne, 1904, 1909).

Of the fifty-seven species recorded from Antipodes Island, two are woody—*Coprosma ciliata* and *C. cuneata*—, forty-three are herbaceous, and twelve are ferns. Of these, *Senecio antipodus* T. Kirk and *Gentiana antipoda* T. Kirk are endemic.

Fourteen peat samples were taken from a steep stream bank 51 in. (127 cm) high by Mr E. G. Turbott*, Auckland Institute and Museum, in November 1950, and given to Botany Division, D.S.I.R. for pollen analysis. The samples were taken at vertical intervals of 4 in. (10 cm) except for a 3-in. interval (8 cm) between samples 4 and 5 (Fig. 2). The samples were macerated in a boiling solution of 10% KOH for 10 min., and after a series of washes and staining with Basic Fuchsin, were mounted in clear glycerine jelly.
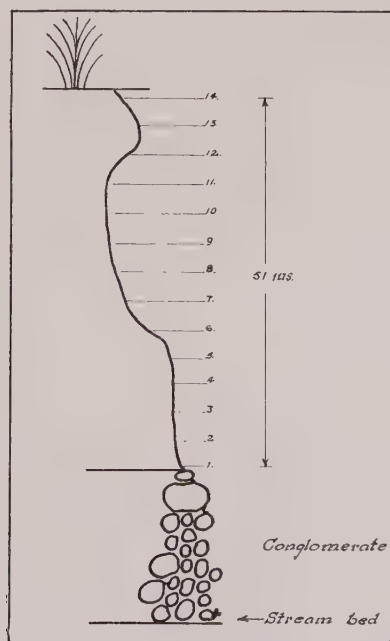

FIG. 2.—Sketch of peat face from which samples were collected. Based on field notes of Mr E. G. Turbott. Redrawn A. A. Sutherland.

Results

Counts of more than 200 fern spores and 100 grass pollen grains were made on all slides except those representing samples 1, 2, 6, 9, and 12. Counts from these were low, and are not included in the pollen diagrams.

Smooth-walled, monolete spores of *Polystichum vestitum* and *Blechnum* spp. were present in great numbers. As many spores of this type could not be accurately identified they are shown in the diagram (Fig. 3) under the general heading "ferns". Other spores identified were those of *Hypolepis millefolia* Hook., *Histiopteris incisa* (Thunb.) J. Smith, *Hymenophyllum* spp. and *Lycopodium varium* R.Br.

The only angiosperm pollen present in any numbers were those of grasses, but even so, these were much lower in frequency than the smooth-walled monolete fern spores. Pollen of other angiosperms indigenous to the island came from *Acaena anserinifolia* (J. R. & G. Forst.) Druce, *Anisotome antipoda* Hook. f., *Callitriche antarctica* Englem., *Carex* sp., *Coprosma* sp., *Gentiana antipoda* T. Kirk, *Helichrysum bellidioides* Willd., *Pleurophyllum criniferum* Hook. f., *Senecio antipodus* T. Kirk, *Stellaria decipiens* Hook. f., *Stilbocarpa polaris* A. Gray. None of these was numerous on any slide.

In addition, there were a few pollen grains each of *Dacrydium cupressinum* Soland., *Podocarpus* spp., and *Nothofagus* spp. on all but two slides. Others of sporadic occurrence were *Phyllocladus* sp., *Haloragis* sp., *Metrosideros* sp., and *Myrsine* sp.

The results (Fig. 3) are based on total pollen, first, because a uniform vegetation has developed on blanket peat, and seondly, because the need to separate tree pollen from non-tree pollen does not arise in this profile.
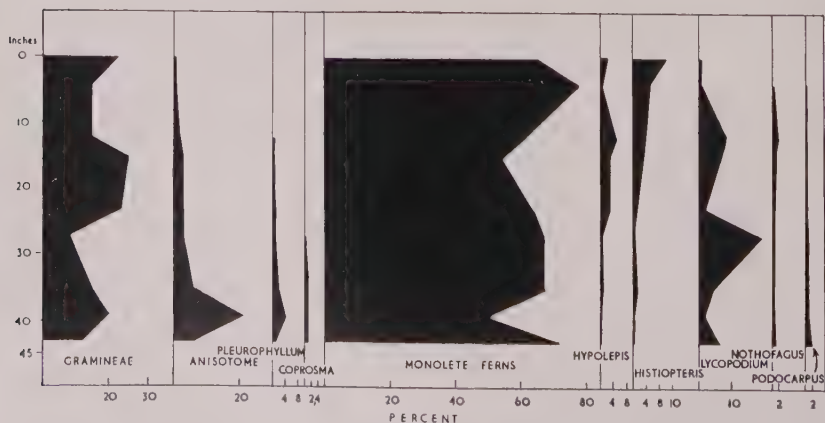

Fig. 3.—Pollen diagram. Antipodes Island.

Discussion

The pollen diagrams indicate little change in the general pattern of vegetation of the peat-forming communities. The fluctuating curves for "ferns" and for Gramineae are considered to represent the changing pattern of a mosaic of vegetation dominated by grass; *Poa litorosa*, and fern, *Polystichum vestitum*. The presence of pollen of *Anisotome antipoda*, *Acaena anserinifolia* and spores of *Hypolepis millefolia*, *Histiopteris incisa*, and *Lycopodium varium* throughout the profile supports this view. The higher frequencies of *Anisotome antipoda* and *Pleurophyllum criniferum* pollen at the base of the profile suggest that wetter soil conditions prevailed at that time.

The presence of gymnosperm and *Nothofagus* pollen is fortuitous, in that these are considered to have been carried by wind from the mainland of New Zealand. The frequencies of these in the profile are too low to suggest otherwise. The matter of long-distance dispersal of pollen has been discussed for the Auckland Islands (Moar, 1958) and the conclusions reached are applicable to the Antipodes Island. Since pollen of *Metrosideros*, *Myrsine*, and *Haloragis* occur sporadically and in frequencies of less than 1% on any slide, and as these genera are not recorded from the island, they must almost certainly be regarded as being wind-borne to the island. Cockayne's (1909) warning that some species may have been overlooked during the few excursions to the island, should, however, not be forgotten.

There is little evidence that would assist in deciding the relative age of the peat; the pollen diagrams do not resemble those of the Snares (Harris, 1953) nor those of the Auckland Islands (Moar, 1958).

However, the unvarying nature of the pollen diagrams when considered in conjunction with the shallow profile suggests that the peat examined is young, and certainly no older than the peats described from the Snares or Auckland Islands.

Acknowledgements

References

Cockayne, L., 1904: A Botanical Excursion during Mid-winter to the Southern Islands of New Zealand. *Trans. N.Z. Inst. 36* : 225-333.

————. 1909: The Ecological Botany of the Subantarctic Islands of New Zealand. Article X in "The Subantarctic Islands of New Zealand." Govt. Printer, Wellington.

FALLA, R. A., 1948: The Outlying Islands of New Zealand. *N.Z. Geogr. 4 2* Govt. Printer, Wellington. N.Z. 127-54.

HARRIS, W. F., 1953: "The Geology of the Snares Islands." Part III Peat samples *N.Z. Cape Exped. Ser., Bull. 13*

MOAR, N. T., 1958: Contributions to the Quaternary History of the New Zealand Flora. 1. Auckland Island Peat Studies. *N.Z. J. Sci. 1*: 449-65.

SPEIGHT, R., 1909: The Physiography and Geology of the Auckland, Bounty, and Antipodes Islands. Article XXX in "The Subantarctic Islands of New Zealand." Govt. Printer, Wellington, New Zealand.

MEASUREMENT OF FLOW IN A SMALL STREAM

By F. W. Taylor, Soil Bureau, Department of Scientific and Industrial Research, Wellington

Summary

In connection with a research project at Taita Experimental Station, it was necessary to build a flow meter to measure stream flows ranging from 0·02 to 10 cusecs and recording accurately at low flows.

The design, construction, and operation of a suitable flow meter are described.

The Problem

As part of a research project designed to measure the balance between incoming and outgoing water and minerals in a stream catchment of 38·4 acres at the Taita Experimental Station, it was necessary to have a continuous record of flow in the stream draining the catchment.

Preliminary estimates of the flow indicated that a range from about 0·02 cusec to about 10 cusec—i.e., a variation of 500 to 1 could be expected and that more than half the total water was discharged at rates of 0·1 cusec or less. Any measuring instrument used, therefore, would have to be capable of measuring the large range of flows anticipated, and especially should be accurate in the low range.

Instrumentation

Extensive enquiries were made to locate a suitable instrument but it was found that none was available that would record accurately over such a wide range of flows.

Stream flows of the order anticipated may be conveniently and accurately measured by using a continuous recording water level meter in conjunction with a 90° V-notch.

The graph so obtained must be re-drawn since the relationship between head of water in a 90° V-notch and flow is represented by the equation

$$Q = 2 \cdot 48 \ H^{2 \cdot 48} \quad (Q = \text{flow in cusec}; \ H = \text{head in ft})$$

when the V-notch is constructed in accordance with British Standard Specification No. 1042.

Level recorders that drive through a varying pitch spiral gear or cams and cam followers and read directly in units of flow are also available. However, as previously indicated, no instrument of this type could be obtained that would read accurately over the range required.

It was therefore decided to select a continuous recording water level meter which could readily be adapted to meet the requirements and use it to obtain preliminary data on the flow in the stream, making refinements to the instrument where experience showed them to be desirable to increase its accuracy.

The instrument selected was a Lea rotary level recorder, manufactured by the Lea Recorder Co. Ltd., Manchester, England (Instrument No. 8182/54). Charts 12 in. long and 10 in. high are mounted on a drum with its axis horizontal. The drum is rotated by a $\frac{1}{16}$ in. diam. stainless steel cable running over a pulley and driven by a float and counterweight. A stylus mounted on rigid horizontal rods is pulled along the horizontal axis of the drum at a speed of $1\frac{1}{2}$ in. per day by a nylon thread driven from a 31-day clockwork motor. The instrument as supplied by the makers is geared to measure heads of 5, 10, 20 ft for cne rotation of the drum. The gears driving the drum were removed and a pulley was fitted directly to the drive shaft to give a direct drive, i.e., one revolution of the drum represents a 10 in. rise in the head of water flowing through the notch. If the head of water rises above 10 in. the drum continues to rotate and heads of over 10 in. are recorded with the same accuracy as those below 10 in. The ability of the instrument to record accurately over a 0 to 20 in. range was the reason for choosing it in preference to other instruments. The alterations to the recorder decreasing the range of the instrument from feet to inches magnified errors due to friction and backlash. It was found that there was a backlash of about $\pm 0 \cdot 25$ in., using the metal stylus and metallized paper supplied with the instrument. By substituting a graphite pencil point for the metal stylus the backlash was reduced to about $\pm 0 \cdot 1$ in. Further modifications, including the substitution of a spiral grooved pulley with one and a half turns of cable running in the groove to eliminate slipping and fitting improved bearings to the drive shaft of the drum are being considered and will be incorporated in another Lea rotary recorder which will replace the present one.

Construction of a V-notch in corrosion resistant material to the standard of British Standard Specification 1042 is expensive and difficult. It was decided to make preliminary records with a steel notch, machined approximately to BSS 1042, and use the knowledge gained from the use of the steel notch to design a permanent installation.

Tables of flow through 90° V-notches for heads of 3 in. to 15 in. are given in BSS 599. Preliminary measurements showed that the head in the V-notch would frequently be less than 3 in.' (flow $0 \cdot 08$ cusec). A notch built in accordance with BSS 1042 was therefore calibrated in the Ministry of Works Hydraulics Laboratory by R. Q. Packard and K. E. Lee. Flows were measured at nine heads ranging from $1 \cdot 076$ in. to $2 \cdot 980$ in., and after plotting the logarithm of the discharge in cusecs against the logarithm of the head, the best fit curve was derived by the method of least squares. The formula obtained was

$$Q = 2 \cdot 11 \ H^{2 \cdot 38}$$

which shows a deviation from the BS, formula ($Q = 2 \cdot 48\ H^{24 \cdot 8}$) of
$+8 \cdot 3\%$ for a head of $0 \cdot 083$ ft (1 in.) and $-2 \cdot 35\%$ for a head
of $0 \cdot 25$ ft (3 in.).

CONSTRUCTION

The weir plate and level recorder were to be installed on a dam con-
structed of rough concrete blocks, incorporating an approximately rect-
angular notch about 5 ft long and 1 ft deep, with a flat crest about
8 in. wide. (A, in Fig. 1.)
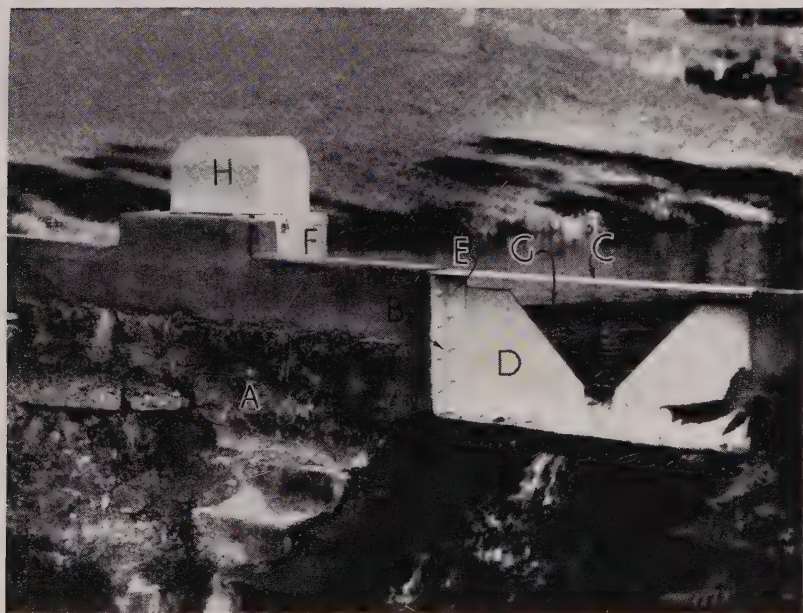
FIG. 1.—General view of weir and recorder from downstream face of dam.
A = old concrete block dam; B = steel angle frame to support weir plate;
C = flat steel brace to prevent distortion of frame; D = steel weir plate;
E = slot for adjustment of weir plate level during installation; F = stilling
chamber housing float and counterweight of level recorder; G = floating
oregon boom; H = metal housing over Lea rotary water level recorder.

A frame 4 ft 6 in. long and 2 ft high to hold the weir plate was made
from 5 in. $\times$ 3 in. $\times$ ⅜ in. mild steel angle. (B, in Fig. 1.) The joints
were electrically welded and a length of 5 in. $\times$ ⅜ in. flat mild steel was
welded on to connect the top edges of the two side members (C in
Fig. 1) providing a brace to prevent distortion of the frame during
transport and fitting to the dam. The face of the frame to which the

plate was to be bolted (the 3 in. wide surface of the angle iron) was machine ground flat to within 0·001 in. to prevent any distortion of the weir plate.

A 16 in. deep 90° V-notch was cut in a flattened mild steel weir plate 4 ft. 8 in. × 2 ft. × ¼ in. (D, in Fig. 1) and the edge of the notch was machined approximately to BSS 1042. Countersunk holes were drilled at 5 in. centres to take ¼ in. countersunk metal thread screws for attaching the plate to the frame. The weir plate and frame were coated with corrosion resistant paint before being placed in position. The steel plate was used from August, 1955, until December, 1957, when it was replaced by a brass weir plate 4 ft 8 in. × 2 ft × ⅜ in., incorporating a 20⅜ in. deep 90° V-notch machined to the tolerances set down in BSS 1042.

On each side of the frame a slot ½ in. high and ¼ in. wide (E, in Fig. 1) was drilled, corresponding to the uppermost holes on the weir plate. This permitted adjustment of the weir plate when it was being levelled.

The height of the dam was raised to accommodate the frame, which was set in wet concrete, so that it projected slightly upstream of the dam face, on bolts already in place, and levelled with a Dumpy level. The bolts were not tightened until the concrete had set, so that stresses on the frame were minimized. The upstream face of the dam was then coated with waterproofed cement plaster, flush with the surface of the frame.

The weir plate was fixed to the frame by the top two bolts and levelled with a Dumpy level. The remainder of the bolt holes were then drilled in the frame to match the holes in the plate. A gasket of ⅛ in. neoprene was cemented to the plate before it was placed in position to ensure a water tight seal between the plae and the frame. The gasket also covered the joint between the frame and the concrete dam. The upstream face of the dam was then plastered again, flush with the surface of the weir plate.

Two right-angle brackets made of 2 in. × 2 in. × ¼ in. mild steel angle, braced with a strip of flat 2 in. × ¼ in. mild steel, were fixed to bolts set in the concrete of the dam to support the water level recorder. A stilling chamber of 20 gauge mild steel (F, in Fig. 1) was fastened to the brackets to house the float and counterweight. The bottom edge of the stilling chamber is about 12 in. below the lowest water level to be measured.

To ensure an area of smooth water upstream from the weir a floating oregon boom (G, in Fig. 1) consisting of two arms about 16 ft long, set at an angle of 60°, was moored in the pond behind the dam. This boom also deflects any stream debris which might otherwise block the notch.

INTERPRETATION OF RECORDS

The weekly graph of head of water against time obtained from the level recorder is re-drawn as a graph showing flow against time, using conversion charts based on the two equations

$$Q = 2 \cdot 11 \ H^{2 \cdot 38} \ \text{for heads up to 3 in.}$$

and $Q = 2 \cdot 48 \ H^{2 \cdot 48}$ for heads above 3 in.

Three conversion charts are used, as follows:

Chart 1 covers flows of 0 to 0·14 cusec
    (= heads of 0 to 3·78 in.)
Chart 2 covers flows of 0·14 to 1·4 cusec
    (= heads of 3·78 to 9·54 in.)
Chart 3 covers flows of 1·4 to 9·217 cusec
    (= heads of 9·54 to 20·375 in.)

The scale of Chart 1 is ten times that of Chart 2, and that of Chart 2 is ten times that of Chart 3. About two-thirds of the yearly runoff comes within the range of Chart 1, while the remainder is concentrated in flash floods of short duration.

The time scale of the flow graph is divided into hourly periods and the rainfall record for each hour, obtained from a recording rain gauge, is plotted on the graph. Total runoff for each 24 hours is calculated by counting squares. The totals are converted to the equivalent in hundredths of an inch of rain on the area of the catchment and plotted on another graph together with the daily rainfall in hundredths of an inch. The runoff during any period can thus be readily compared with the total amount of rain falling within the catchment.

ELECTRIC FISHING WITH PULSATORY DIRECT CURRENT

By A. M. R. Burnet, Fisheries Research Laboratory, Marine Department

Summary

The attractive effect on fish of pulsatory direct electric current is a combination of electrotaxis and forced swimming. With trout, the most efficient pulse frequency for electronarcosis and electrotaxis is between 50/sec and 100/sec, while for forced swimming it is between 2/sec and 5/sec.

A dual frequency pulse is described and is the most efficient of a number of pulse types used in field trials.

Introduction

This paper outlines the further development of the electric fishing machine described by Burnet (1952b). The original machine was not suitable for the capture of trout, and a larger version, with a gasoline engine power unit, was constructed.

Field use of this larger machine suggested other improvements. As regular sampling of the trout and eel population in a small stream was in progress, it was possible to assess the effects of modifications, using the rate of catch of fish as a measure.

Some laboratory tests were also made.

The Field Trials

Methods

Only a proportion of an eel or trout population is caught with an electric fishing machine, and indirect methods must be used to estimate the total population of a sample area. As the proportion caught in one sampling is usually over 50% the technique of diminishing returns is used to estimate the total population in the sample area. The theory of this technique has been described by De Lury (1947).

In practice the sampling area is covered two or three times and the captured eels and trout removed each time. If it is assumed that a constant proportion P of the remaining population is caught each time, then it can be shown (Burnet, 1952a) that:

$$C_n = KP (1 - P)^{n-1}$$

where C_n is the nth catch
   K is the total population
   P is the proportion of the remaining population caught each time.

Table 1.—Rate of Catch of 8 in. and over Trout in the Doyleston Drain.

Pulse Type	Form	Frequency (pulses per sec.)	Duty Cycle	Voltage	Power (watts)	Date	1st Catch	2nd Catch	3rd Catch	P
A	Capacitor discharge (20 microfarads)	20	0·04	610	73	21/12/53	14	7		0·50
						22/12/53	17	10		0·41
						7/1/54	29	15		0·48
										Av. 0·46
B	Capacitor discharge (40 microfarads)	20	0·07	450	80	19/2/54	14	3	1	0·75
						21/4/54	47	13	2	0·78
						22/4/54	34	5	0	0·85
										Av. 0·78
C	Rectilinear pulse	20	0·25	170	29	28/6/54	21	3	2	0·76
						9/8/54	41	7		0·83
						9/8/54	38	9		0·76
						6/1/55	38	8	3	0·74
										Av. 0·77
D	Rectilinear pulse (dual frequency)	2·5 / 60	0·80 / 0·25	170	23	9/3/55	15	0	1	0·97
						29/3/55	24	4		0·83
						30/3/55	27	0		1·00
						31/3/55	27	2		0·93
										Av. 0·93
E	Rectilinear pulse (dual frequency)	2·5 / 60	0·80 / 0·25	300	85	27/6/55	21	1		0·93
						28/6/55	20	3		0·95
						28/6/55	12	1		0·85
						3/5/56	31	4		0·92
										0·87
										Av. 0·90

With two successive catches, this formula can be solved for *P*, the rate of catch, which is a function of the efficiency of the catching method. The values obtained for *P* are used to compare the effect of various pulse types.

The field trials are all on similar sections of small streams, such as the Doyllston Drain, shown in Fig. 1. This stream is between 12 and 14 ft wide, and the water depth is from 6 to 12 inches. The cover for trout and eels is provided by overgrown and undercut banks.

Results

Trout, 8 Inches and Over

The results obtained with five different types of pulse are shown in Table 1. In cases where there were more than two catches, the data were plotted on log by linear graph paper, and a straight line fitted by eye.

Fig. 1.—The electric fishing machine in use. In the foreground are the pulse forming unit (weight 14 lb), petrol motor-high frequency alternator (weight 38 lb), and the cable reel for 200 yards of 40/0076 P.V.C. insulated cable (weight with electrode 30 lb.).

In the stream can be seen the 2 ft × 3 ft brass gauze earth mat (weight 3 lb), a floating live fish container and the operator, wearing rubber gloves, holding the electrode, and a wire gauze hand net. The photograph was taken at a typical section of the Doyleston Drain, the small stream used to obtain the results presented in this paper.

Pulse Type A. (20 pulse/sec 0·04 duty cycle* 610 volts)

This pulse produced a violent reaction by the trout. They continued to vibrate at the pulse frequency after being removed from the water, and were often observed to swim on through the field even though they had lost balance.

Morgan (1953) observed that as the duty cycle of a pulse increases the reaction becomes less violent, and approaches that of pure direct current. It was therefore decided to try the effect of a longer pulse.

Pulse Type B. (20 pulse/sec 0·07 duty cycle 450 volts)

This pulse has, according to laboratory experiments (*infra vide*), the same electronarcotic effect as pulse type A.

Pulse B, however, gives a considerably higher rate of catch, *P*.

Pulse Type C. (20 pulse/sec 0·25 duty cycle 170 volts.

The electronarcotic effect of this pulse is significantly less than for pulses A and B. To give an equivalent effect Pulse type C should have a potential of 330 volts.

In practice, therefore, a fish has to be closer to the electrode before the electronarcotic effect is apparent, and this was observed in the field. However, the results show that Pulse type C is just as effective in catching trout as Pulse type B.

It is suggested that the longer pulse is more effective in attracting trout. If the attractive effect is the most useful feature of pulsatory D.C., the frequency of the pulse should be adjusted to the optimum for attraction.

Pulse Type D. dual frequency $\begin{cases} 2 \cdot 5 \text{ pulse/sec } 0 \cdot 8 \text{ duty cycle} \\ 60 \text{ pulse/sec } 0 \cdot 25 \text{ duty cycle} \end{cases}$ 170 v.

A basic frequency of 2·5 pulse/sec was chosen as it approximates to the natural swimming frequency of trout (*infra vide*). The results of Groody *et al.* (1952), Morgan (1953), and Haskell *et al.* (1954) indicate that at a frequency of 2·5 pulse/sec the duty cycle should be 0·8. As this was beyond the capabilities of the equipment, the 0·8 on time of the 2·5/sec pulse was broken up into a 60/sec pulse with a duty cycle of 0·25. This pulse is illustrated in Fig. 2. A similar pulse is described by Haskell and Adelman (1955).

This dual frequency pulse gave a higher rate of catch.

Pulse Type E. (dual frequency pulse of 300 volts)

The higher voltage had no measurable effect in the test stream, but did make the equipment effective in larger streams.

---

*Duty Cycle = the proportion of the time during which the current is flowing.
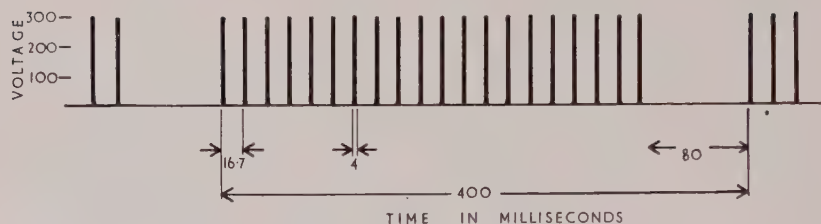
FIG. 2.—A diagrammatic representation of the output of the dual frequency
pulse generator.

TROUT OF LESS THAN 8 IN.

The rates of capture for smaller fish are shown in Table 2.

Changes in pulse length and frequency have not altered the rate of catch for trout of 3 inches in length.

A slight increase in the rate of catch is shown with Pulse type F which is identical with Pulse type E, except that the basic frequency was changed from $2 \cdot 5$/sec to 5/sec.

It can be seen that, for a given pulse, the rate of catch varies with the size of the trout. This is, of course, an important factor to watch when estimating total populations.

EELS

The effect of the change to the dual frequency pulse on the rate of catch of eels is shown in Table 3. Eels are not attracted as positively as trout, but they have been observed to swim towards the positive electrode when the dual frequency pulse is used. The efficiency of collecting is increased and a saving in time occurs as the eels tend to be forced out of cover, and the operator does not have to wait for stunned eels to drift out.

LABORATORY EXPERIMENTS

The Optimum Pulse Frequency for Electronarcosis

In the previous experiments (Burnet, 1952b) the pulse time was kept constant, and thus, as the frequency increased, the duty cycle increased until it became unity. Therefore, the curves obtained with a constant pulse time approach an asympote equal to the direct current narcotizing voltage. The effects of variation in frequency are shown more clearly by making the pulse time a constant proportion of the frequency, i.e. keeping the duty cycle constant.

Then $Power\ used = \dfrac{(Voltage)^2}{Resistance} \times duty\ cycle\ (watts).$

Table 2.—Rate of Catch for Small Trout.

Pulse Type	Date	1st Catch	2nd Catch	3rd Catch	P	Average length of Trout (in.)
A	21/12/53	17	5	—	0·71	3·1
A	21/12/53	13	6	9	0·5	3·1
					Av. 0·6	
C	6/1/55	38	13	2	0·68	3·3
C	7/1/55	25	13	5	0·50	3·3
C	18/1/55	44	13		0·70	3·3
C	20/1/55	52	14		0·73	3·3
					Av. 0·65	
E	7/4/55	203	76		0·63	2·7
E	6/1/56	20	8		0·60	3·2
E	10/1/56	13	5		0·62	3·2
E	16/1/56	38	9		0·75	3·2
					Av. 0·65	
B	21/4/54	28	5	2	0·81	5·7
D	9/3/55	28	3	3	0·79	5·0
D	30/3/55	138	28	—	0·80	5·0
E	27/6/55	19	4		0·79	5·9
E	28/6/55	34	5		0·85	5·9
E	28/6/55	25	5		0·80	5·9
					Av. 0·81	
F	30/7/56	15	1		0·93	6·3
		16	3		0·82	6·3
		21	1		0·92	6·3
					Av. 0·90	

Table 3.—Rate of Catch for Eels in the Doyleston Drain.

Pulse Type	Date	1st	2nd	3rd	P
B	26/3/54	25	13	7	0·48
	6/4/54	28	13	2	0·68
C	16/12/54	33	11	—	0·67
D	29/3/55	39	7	8	0·72
	30/3/55	41	9	—	0·78
	31/3/55	34	3	—	0·91

The pulses were produced by a multivibrator square wave generator. A single fish was used for each series of measurements as it was found that, after the first few measurements, reproducible results could be obtained. Care was taken not to exceed the electronarcosis potential, the current was maintained for less than 10 sec, and the fish was allowed a few minutes to recover. Up to 30 measurements were made with each fish.

A series of pulse frequencies, as shown in Fig. 3, was chosen, and the electronarcosis voltage determined for each frequency. The series of measurements was repeated three times and the average for each
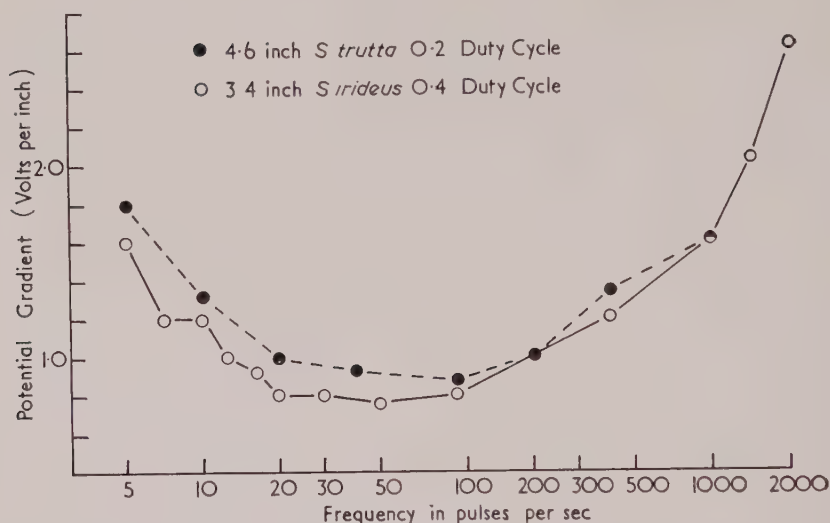
Fig. 3.—The relation between the frequency of the pulse and the potential gradient required to paralyse at a constant duty cycle. (Head to cathode.)

frequency plotted on the graph. The electronarcosis point was determined by increasing the potential gradient, as measured on an oscillograph, in steps of 0·2 volts/inch, until the fish lost balance, and made no attempt to recover.

The results are shown in Fig. 3. As both the duty cycle and the resistance are constant, the power is proportional to the voltage squared. The optimum frequency lies between 50 and 100 pulse/sec.

The Optimum Pulse Length for Electronarcosis

Using the same procedure, the potential gradient required to produce electronarcosis at various duty cycles was determined. The results are shown in Fig. 4. It was calculated that the minimum power is used by the shortest pulse time.

The Natural Swimming Frequency

A number of measurements of the natural swimming frequencies of Brown trout was made, using a cine camera. The smaller fish were photographed in a tank 25 in. long, and the larger fish in the still water of a pond. The results are shown in Table 4. It was not possible to measure frequencies for trout swimming at their maximum speed, which Gray (1953) gives as 7 ft/sec for a 9 in. fish. Velocities of 12 and 25 in/sec were recorded for the 3·1 in. trout, but in both cases the measurements were made on part of a glide which followed a powerful thrust with the tail.
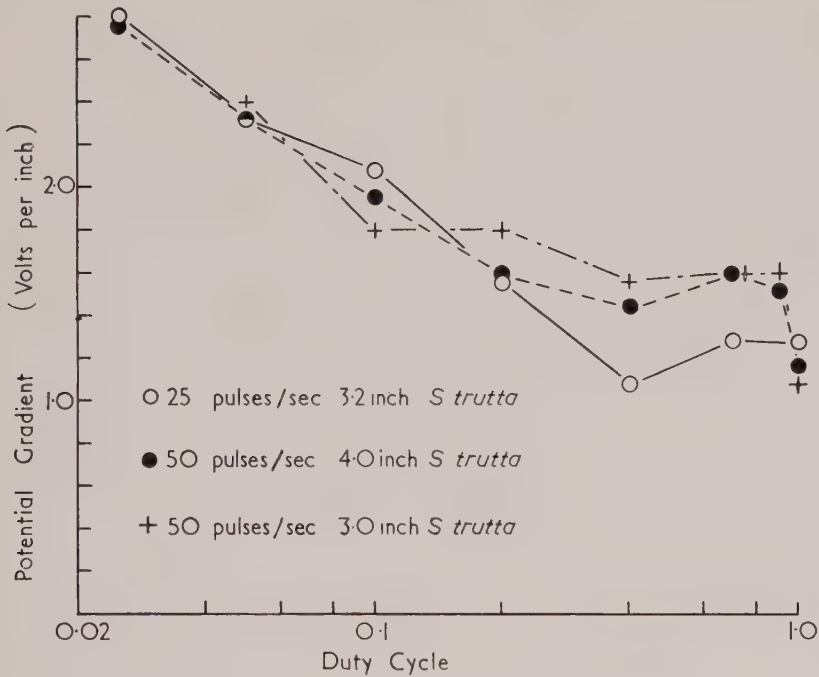
FIG. 4.—The relation between duty cycle and potential gradient required to paralyse at a constant frequency. (Head to anode.)

TABLE 4.—Frequency of Natural Swimming Undulations.

Fish		Length (in.)	Frequency (waves per sec.)	Velocity (inches per sec.)
Brown Trout No. 1	a	3·1 Free swimming in tank	3·2	5
	b	3·1 Free swimming in tank	4·0	7
Brown Trout No. 2	a	4·5 Free swimming in tank	3·2	5
	b	4·5 Free swimming in tank	5·3	7
Brown Trout No. 3		8·5 Free swimming in tank	2·7	10
Brown Trout No. 4		16·3 Free swimming in pond	2·0	—
Brown Trout No. 5		18·0 Swimming in field of electric fishing machine	2·7	—

THE EFFECT OF ELECTRIC FISHING ON A TROUT POPULATION

With experienced operators, the number of fish killed is insignificant. It is important that handling, and exposure to the electric current, be kept to a minimum (e.g. the use of wire gauze hand nets helps to protect the fish from the electric current).

The occurrence of delayed mortality has not been investigated, except in one instance when a number of large trout were held in a pond for two days after shocking and there were no deaths. The regular sampling, at 2- or 3-monthly intervals, of the trout population of a small stream, has shown a normal mortality rate even though some individual trout have been captured 9 times.

It is important that the capture and handling should not affect the growth rate. Meyer (1953) has suggested that moderate exposure to both A.C. and D.C. currents increases the growth rate.

So far, in the work that is being done with the fishing machine, there is no indication of any significant effect on the growth rate.

CONCLUSIONS

The Attractive Effect

There appear to be two factors contributing to the attractive effect, forced swimming and galvanotaxis. The higher efficiency of the low frequency pulses, the frequency of which is closer to the natural swimming frequency ,indicates that the pulse is triggering the natural swimming rhythm of the nervous system. Forced swimming is directional when there is also galvanotaxis.

Galvanotaxis is the attempt by a fish to line itself up with the flow of electric current. It has been shown by Van Harreveld (1938), Haskell *e tal.* (1954), and Lethlean (1953) that salmonids placed at right-angles to the electric current flow, bend so that the fish becomes concave on the side towards the anode. If a fish in this condition can be forced to swim, it must move towards the anode.

It follows that the longer the on time of the pulse, the better will be the control of the direction of swimming. This is the most likely explanation for the higher efficiency of the longer pulse times, found in the field trials.

The Advantages of Pulsatory Direct Current

Pulsatory D.C. simplifies the collection of fish. The very positive attraction readily brings trout out from under cover. It concentrates the trout, immobilizing them close' to the operator.

The interrupted nature of the current has a practical advantage over pure D.C., because' normal types of switches can be used.

Choice of Pulse Frequency and Equipment Design

The most effective pulse is one with a frequency of 2 to 5 pulse/sec and a duty cycle of 0·8.

It has been shown, Taylor *et al.* (1957) that a pulse of 96/sec 0·33 duty cycle is the most efficient for producing a leading effect. Thus

there can be a power saving if the on time of the 2·5/sec pulse is broken into a 100/pulses/sec with a duty cycle of 0·33.

To achieve this power saving, energy must be stored, and delivered in short bursts. The major practical difficulty is the efficient storage of this energy. The weight of the components required to store the energy offsets, to some extent, the reduction made in the weight of the motor-generator unit. The most efficient pulse times involve the use of high voltages, increasing the safety problems.

Equipment

The machine used to obtain the results presented, is shown in Fig. 1. It is a $\frac{1}{3}$ h.p. two-stroke engine driving a 500 watt high frequency alternator. The A.C. is rectified to D.C. by thyratrons, which are controlled by the pulse forming multivibrator circuits. With a single positive electrode, and an earth return, this machine, producing 85 watts of pulsatory D.C., is effective for trout of 3 in. and over, in streams of up to 15 ft wide and 3 ft deep.

With an electrode system of two negative electrodes, and a central positive electrode attached to a boat, the equipment is used in sreams of up to 20 ft wide and 6 ft deep.

Acknowledgements

References

Burnet, A. M. R., 1952a: Studies on the Ecology of New Zealand Long-finned Eel *Anguilla dieffenbachii* Gray. *Aust. J. Mar. Freshw. Res. 3* : 32-63.

————, 1952b: Studies on the Ecology of the New Zealand Freshwater Eels 1. Design and Use of an Electric Fishing Machine. *Aust. J. Mar. Freshw. Res. 3* : 111-25.

De Lury, D. B., 1947: On the Estimation of Biological Populations. *Biometrics. 3* : 145-67.

Gray, J., 1953: "How Animals Move." 114 pp. C.U.P.

Groody, T.; Loukashkin, A.; Grant, N., 1952: A Preliminary Report on the Behaviour of the Pacific Sardine (*Sardinops caerulea*) in an Electrical Field. *Proc. Calif. Acad. Sci. 27* : 311-23.

Harreveld, A. van, 1938: On Galvanotropism and Oscillotaxis in Fish. *J. exp. Biol. 15* : 197- 208.

HASKELL, D. C.; MACDOUGAL, J.; GEDULDIG, D., 1954: Direct Current Electric
          Field. *N.Y. Fish. Game. J.* *1* : 47-64.

HASKELL, D. C.; ADELMAN, W. F., 1955: Effects of Rpaid Current Pulsations
          on Fish. *N.Y. Fish. Game. J.* *2* : 96-105.

LETHLEAN, N G., 1953: An investigation into the Design and Performance of
          Electric Fish Screens and an Electric Fish Counter. *Trans.*
          roy. Soc. Edinb. *62* : 479-526.

MEYER, P. F., 1953: Beeinflusst die Elektronarkose Lebensfähigkeit and Wachstum
          der Fische? *Der Fischwirt.* *3* *(7)* : 225-8.

MORGAN, M. E., 1953: The Response of a Tropical Fish to Direct Current and
          its Application to the Problems of Electrofishing in Sea Water.
          Pacif. Sci. 7 : 482-92.

TAYLOR, G. N.; COLE, L. S.; SIGLER, W. F., 1957: Galvantoaxic Response of Fish
          to Pulsatory Direct Current. *J. Wildlife Mgmt. 21* : 201-13.

MARINE FOULING AT THE PORT OF AUCKLAND

By T. M. SKERMAN, New Zealand Oceanographic Institute, Department
of Scientific and Industrial Research, Wellington

Summary

Investigations of marine fouling at the Port of Auckland indicate that the
following are the principal species involved: Diatoms; *Navicula Grevillei* (Ag.)
Cleve: Hydroids; *Tubularia larynx* E. & S., *Pennaria australis Bale.,* ?*Obelia geni-
culata* (L.): Polyzoa; *Bugula neritina* (L.), *B. flabellata* (Thompson), *Scrupo-
cellaria* sp.: Serpulids; *Hydroides norvegica* Gunnerus; Molluscs; *Ostrea* cf. *O.
sinuata* Lamarck, *Anomia walteri* Hector: Barnacles; *Balanus amphitrite* var. *cir-
ratus* Darwin, *B. trigonis* Darwin, *Elminius modestus* Darwin: Ascidians; *Diplo-
soma macdonaldi* (Herdman), *Microcosmos kura* Brewin. From experimental data
accumulated during a two-year survey, the relative abundance, seasonal settlement,
and growth of these forms on non-toxic test panels are outlined.

Intensive settlement, in which the above barnacles, polyzoans, and the hydroids
Tubularia and *Pennaria* predominate, occurs on surfaces from November until
the end of April; *Elminius, Tubularia,* and ?*Obelia* are the most conspicuous
components of the relatively lighter winter fouling.

Some consistent differences in the initial fouling of test panels were noted
between the three experimental stations. Heaviest barnacle and hydroid settlement
occurred at Kauri Point, where serpulids, polyzoans, oysters, and ascidians were
uncommon. At Calliope Wharf (Devonport), where barnacle settlement was
lightest, there was a high incidence of the serpulid *Hydroides* and polyzoans,
particularly *Bugula neritina.* Most species were represented on panels at North
Head, where the highest intensity of winter fouling was observed.

In the progressive development of aged fouling communities, barnacle and
hydroid populations, which were usually the initial colonizers of new surfaces,
failed to survive on the prolonged immersion of panels; communities ultimately
became dominated by a *Microcosmos-Ostrea* association. Neither of these species
attached to the surfaces of the newly immersed panels.

Factors influencing the settlement of individual species and those contributing
to qualitative differences in fouling between sites and to the intensity of fouling
in the port are discussed.

INTRODUCTION

The aims and experimental procedures of a general survey of marine
fouling within the major ports of New Zealand have been outlined in
a previous paper (Skerman, 1958b), which included an account of
fouling at Port Lyttelton. Results are presented here of similar investi-
gations made from 1954 to 1956 in the North Island Port of Auckland.

Locality

Auckland Harbour lies at the mouth of the Waitemata River at the south-western side of the Hauraki Gulf, North Island. Extending 54 miles in an east-west direction at an average width of one mile, it has a total area of 77 square miles, and, as no great amount of fresh water enters the region, it is generally regarded as a tidal estuary. The commercial Port of Auckland (Fig. 1) is situated near the mouth of the harbour and lies between Kauri Point and a line from North Head and Bastion Point as its eastern boundary. An account of the general topography of the harbour has been given by Hounsell (1935) in a report of local hydrological and meteorological observations.
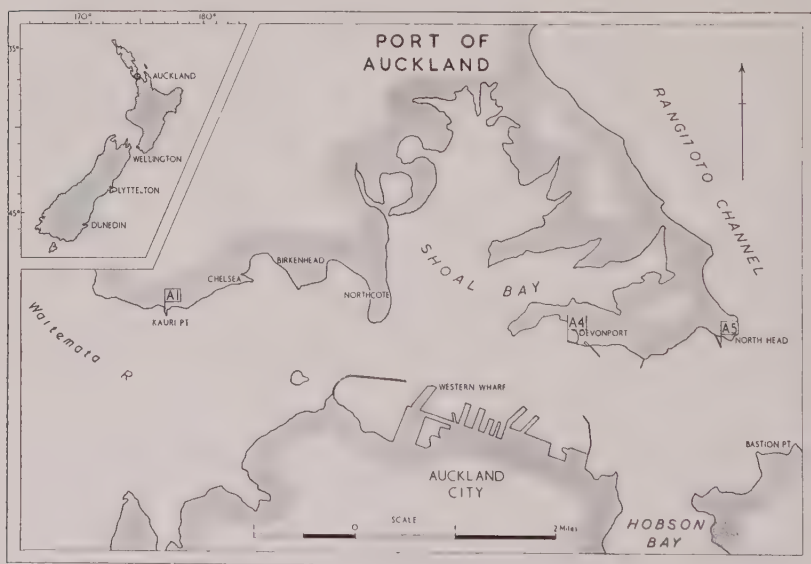

Fig. 1.—Port of Auckland, North Island, New Zealand. Locality map showing sites of experimental stations.

Auckland ranks as second port of New Zealand in regard to aggregate tonnage of shipping entered. In 1956, 5,299 entries (overseas and coastal) were recorded, amounting to a total inwards traffic of 3,069,048 net tons, or 21% of the total tonnage entering all New Zealand ports. Of the total overseas shipping tonnage entering New Zealand ports in the same year, 27·8% was recorded at Auckland.*

*N.Z. Official Year Book, 1958. Govt. Printer, Wellington.

A considerable number of marine biological studies have been made on the distribution and zonation of intertidal species on coasts in the vicinity of the Hauraki Gulf (for summary, see Dellow, 1955). Powell (1937) defined animal bottom-communities of the harbour region in an ecological survey based on Hounsell's (1935) hydrological observations, and Oliver (1923) included in his descriptions of New Zealand marine littoral communities accounts of certain associations in Auckland Harbour. A prolonged investigation into the deterioration of timber, concrete, and metal materials in sea water was conducted in the harbour from 1919 to 1950 as part of a world-wide survey by the Institution of Civil Engineers (Great Britain), but in the series of reports published (D.S.I.R., U.K.) little attention was given to the specific fouling organisms. Bacteriological surveys of harbour and western Hauraki Gulf waters have been made by Wallace and others (1953a, 1953b, 1958) to determine the density and dispersion of locally discharged sewage. An investigation of primary fouling films on submerged surfaces, and their effect on the settlement of macro-fouling organisms during the summer period of maximum fouling intensity has been reported by Skerman (1956).

Experimental Sites (Fig. 1)

Initially, five experimental stations were established throughout the lower harbour from Kauri Point to North Head, with three on the northern shore (Kauri Point Wharf = A1, Calliope Wharf = A4, North Head Wharf = A5), and two by the city wharves on the southern shore (Western Wharf = A2, and Princes Wharf = A3). As much tampering and damaging of frames and panels occurred at both south shore stations during the first few months of operation, these were abandoned in 1954. Frames at Kauri Point, Calliope Wharf, and North Head were then fixed to wharf scaffolding so that they were accessible only from a boat. All frames were set at a depth of 1 ft below E.L.W.S.

Immersion Schedule

The schedule of withdrawal and replacement of panels was maintained on an identical basis to the one previously adopted in the Lyttelton investigations. These operations were carried out by officers of the Fisheries Inspection Patrol under the superintendence of the Auckland District Inspector of Fisheries, Marine Department, who also arranged the dispatch of panels to the Wellington laboratory.

Hydrological Factors

Sea Temperatures.—Records of sea-surface temperatures at the port were made in conjunction with the experimental programme and have been reported previously (Skerman, 1958a). In 1954, mean monthly temperatures were found to be highest in February (22·1° C) and lowest in August (11·4° C), and in 1955 February (23·1° C) and July (11·3° C). Mean annual ranges were thus 11·7° C and 11·8° C in the respective years, while extreme summer-winter ranges were 14·4° C

and 13·8° C. Records for earlier years were given by Hounsell (*op. cit.*), who also stated that the daily range in sea temperatures in the harbour did not exceed 2° C on the average, but that on days of bright, calm weather, temperatures may rise sharply as much as 5° C.

TIDES AND WINDS.—Tides are of the semi-diurnal type, and vertical ranges vary from 5 ft 6 in at neaps to 12 ft at springs. According to Hounsell, tidal currents differ considerably at various parts of the harbour, being greatest off projecting points. As the two experimental stations at Calliope (A4) and North Head (A5) wharves were located in such positions, it may be expected that the maximum current velocities given by Hounsell may have been of normal occurrence at these sites. It is probable that less severe currents were experienced at A1, where some shelter would have been derived from the offlying headland of Kauri Point. All experimental sites may be regarded as having been exposed to the influences of the prevailing westerly to south-westerly winds.

SALINITY.—Available information on annual or short-term ranges in salinity of Auckland Harbour waters is very inadequate, and unfortunately it was impracticable to carry out such determinations in conjunction with the biological programme. In his 1935 paper, Hounsell gave results of a small number of approximate salinity determinations of samples taken from various positions in the harbour, and further figures were quoted by Powell (1937, p. 373). During a bacteriological survey of harbour waters made by the D.S.I.R. Government Analyst (Auckland) on September 7 1953, a number of surface water samples were taken and subsequently analysed for salinity; these results are summarized below.

*Weather: showery, Force 4 wind. Nor'-westers for previous few days, with occasional light showers.

High tide: 6.59 a.m.

Sample	Position (refer to Fig. 1)	Time	Chloride ions p.p. 100,000
		a.m.	
1	Off Kauri Point Wharf	10·08	1660
2	Off Kauri Point	10·28	1663
3	In main channel, west of Chelsea	10·32	1679
4	In main channel, east of Chelsea	10·35	1706
5	In main channel, off Birkenhead	10·38	1732
6	In main channel, off Northcote	10·41	1687
7	In main channel, off Shoal Bay	10·45	1671
8	Off Calliope Wharf	11·10	1784
9	Off North Head Wharf	11·34	1834
		p.m.	
10	Off Western Wharf (City Wharves)	12·43	1766

Despite its scantiness, the existing data are not in conflict with Houn-sell's supposition (p. 269) that there may be a considerable amount of variation in the salinity of Upper Harbour (i.e., west of Kauri Point) waters throughout the year; in this region, rainfall and river outflow may be expected to give rise to periodic conditions of lower salinity than in waters of the lower reaches of the harbour.

SPECIES LIST

A list of the species recorded from experimental panels at the three sites is given as follows:

ALGAE
>   Bacillariophyceae
>>   *Navicula Grevillei* (Ag.) Cleve

COELENTERATA
>   Hydrozoa
>>   *Tubularia larynx* E. & S.
>>   *Pennaria australis* Bale
>>   *?Obelia geniculata* (L.)

POLYZOA
>>   *Bugula neritina* L.
>>   *Bugula flabellata* (Thompson)
>>   *Scrupocellaria* sp.

POLYCHAETA
>   Serpulidae
>>   *Hydroides norvegica* Gunnerus
>>   *Galeolaria hystrix* Morch

MOLLUSCA
>   Pelecypoda
>>   *Ostrea* cf. *O. sinuata* Lamarck
>>   *Anomia walteri* Hector
>>   (*"Mytilus"* or) *Perna canaliculus* (Gmelin)
>>   *Musculus impactus* (Hermann)

CRUSTACEA
>   Cirripedia
>>   *Elminius modestus* Darwin
>>   *Balanus amphitrite* var. *cirratus* Darwin
>>   *Balanus trigonis* Darwin

TUNICATA
>   Ascidiacea
>>   *Corella eumyota* Traustedt
>>   *Asterocarpa cerea* (Sluiter)
>>   *Microcosmos kura* Brewin
>>   *Styela plicata* (Lesseur)
>>   *Botryllus schlosseri* (Pallas)
>>   *Diplosoma macdonaldi* (Herdman)
>>   *Botrylloides leachi* Savigny
>>   *Aplidium* (*Amaroucium*) *phortax* Michaelsen

Monthly Settlement

From the evidence of panels immersed during each month of the year, a summary of settlement during 1954 and 1955 at Kauri Point (A1), Calliope Wharf (A4), and North Head (A5) is given as follows:

January

Heavy settlement by the barnacle *Elminius modestus* occurred at all stations. Numerous epizoic colonies of *Tubularia larynx* developed in association with the closely packed barnacle populations at A1 and A5, but only light settlement of this form took place at A4. Large numbers of the serpulid, *Hydroides norvegica*, absent at A1, appeared on panels at A4 and A5. Further features of A1 panels qualitatively distinguishing them from those at the other sites were the abundant both these sites in 1955, were rare in 1954. As in January, settlement of *Pennaria australis*. While only a few colonies of the polyzoan *Bugula neritina* developed at A5, this species was most conspicuous at A4.

February

Dense *Elminius* settlement was again characteristic at all stations. Heavy settling of *Balanus* was noted at A1 in both years, but this barnacle appeared only sporadically at A4 and A5. Extensive *Tubularia* growth occurred at A1 and A5, while few colonies appeared at A4. *Hydroides* settlement continued in considerable density at A4 and A5 in both years, while *Bugula flabellata* colonies, common at both these sites in 1955, were rare in 1954. As in January, settlement of *Pennaria* was confined to panels at A1. Scattered individuals of the solitary ascidian, *Corella eumyota* appeared at A5, together with a few colonies of the compound form, *Diplosoma macdonaldi*.

March

Heavy barnacle settlement continued, with *Elminius* dominant at all sites, whereas *Balanus,* as formerly, was abundant only at A1. *Tubularia* settlement was heaviest at A5. Few polyzoan colonies consisting of *Bugula neritina* at A4 appeared in 1954, but these forms were conspicuous in the following year, with *B. flabellata* prominent at A1 and A5, *B. neritina* again at A4. A comparatively heavy set of *Hydroides* took place at A4 and A5 in 1954, and a few of these serpulids were noted for the first time at A1. In 1955, *Hydroides* appeared only at A5. Rarer forms were the compound ascidian, *Botryllus schlosseri* at A4 in each year, and *Pennaria* at A1 in 1954, and at A1 and A5 in 1955.

April

With a marked falling-off in barnacle settlement, which was mainly restricted to panels at A1, *Tubularia* remained the dominant organism on panels withdrawn at the end of this month, although colonization by this species was substantially poorer in 1955. Calcareous tubes of *Hydroides* were prominent on panels at A4 and A5 in 1954, but this form was absent in the following year. *Bugula neritina* colonies were again confined to A4 panels, while those at A5 bore *B. flabellata*. No polyzoans were recorded from A1. A large number of *Corella* settled at A4 in 1954, and sparsely at A5 in 1955. In both years, *Anomia walteri* settled commonly at A5.

May

In 1954, a dense settlement of the hydroid ?*Obelia geniculata* took place at all stations. This species was much less prominent in 1955. In 1955, panels at A1 and A4 were almost devoid of growth apart from a few *Elminius* and scattered small *Tubularia* colonies, whereas relatively heavy settlements of both *Elminius* and *Tubularia* occurred at A5 in both years. *Anomia* settled abundantly at A5 in 1955.

June

With the exception of *Anomia,* a similar pattern of settlement to that in May continued. In 1954, the hydroid *?Obelia* was again the dominant feature of all panels, with only a few *Elminius* present. Many more of these barnacles settled in 1955, particularly at A5. A heavy set of *Tubularia* took place at A1 in 1954, and at least a few colonies of this hydroid developed on all other panels immersed during this month.

July

Settlement of most forms noted in the previous two months continued. In 1954, panels were dominated by numerous colonies of *?Obelia,* while *Elminius* and *Tubularia* constituted the only forms found in 1955. A particularly heavy colonization of the panel at A5 by *Elminius* took place in 1955.

August

There was very little settlement during this month in both years. In 1954, no *Elminius* appeared at A1 or A4, but heavy settlement occurred at A5. A1 and A4 panels in this year were practically devoid of growth apart from a few small *Tubularia* colonies and stalked protozoans at A1 and a light settlement of *?Obelia* at A4. *Tubularia* also settled at A5. In 1955, *Elminius* attached at all stations and there was more widespread *Tubularia* settlement at A1 and A5. As in the previous months, *?Obelia* was uncommon in 1955.

September

In 1954, the predominant growth on panels at A1 and A5 consisted of *Tubularia* colonies, but at A4, in place of this form were numerous polyzoans, *Bugula neritina* and *B. flabellata.* Extensive colonial growth of *Diplosoma* also occurred on the A4 panels, which also bore a few *Elminius.* A number of ascidians *Asterocarp cerea* were present at all stations. The serpulid *Galeolaria hystrix* settled in small numbers at A4 and A5, and panels at these stations also bore many colonies of the diatom *Navicula Grevillei.* In 1955, hydroid growth (*Obelia*) was common on all panels. As in 1954, *Bugula neritina* appeared at A 4 and *B. flabellata* at A5. Numerous *Diplosoma* colonies were found on the A4 panel, and both this and A5 carried the characteristic clumps of *Navicula.* More widespread colonization by *Elminius* took place in 1955, but only a few *Galeolaria* serpulids settled.

October

Settlement on panels during this month was similar in both years. At A1, *Tubularia* colonies and *Elminius* were the only forms present, but at A4, where the heaviest amount of growth developed, panels were dominated by *Scrupocellaria* sp. and *Bugula neritina.* Also settling abundantly at A4 was the simple ascidian *Corella,* which was absent at other stations. The lighter settlement prevailing at A5 consisted of a few *Tubularia colonies, Elminius,* and *Galeolaria.*

November

Panels withdrawn from all stations at the end of this month bore very heavy growth, in which *Tubularia* predominated. Intensive settlement by *Elminius* and *Balanus amphitrite* var. *cirratus* at A1 resulted in surfaces of panels being completely obscured by the closely packed barnacle populations. There was evidence that a similarly heavy barnacle set had occurred at A5, but few of these barnacles remained alive beneath the extensive undergrowth of *Tubularia* colonies. Few barnacles (*Elminius* and *Balanus trigonis*) settled at A4, where, in addition to *Tubularia,* numerous *Bugula neritina* and *B. flabellata* colonies developed. Ascidians were represented by many *Corella* at A4, and several colonies of the compound form *Diplosoma* at both A4 and A5. Further differences in settlement at these two sites were shown by the presence of *Anomia* at A4, and *Hydroides* at A5.

December

At all stations, heavy barnacle settlement prevailed, with *Elminius* as the dominant species, numerous *Balanus amphitrite* var. *cirratus* at A1 and A5, and a few *B. trigonis* at A1 and A4. Epizoic settlement consisted of many *Tubularia* colonies at A1 and A5; *Bugula flabellata* colonies developed at A5.

These data from monthly panels have been included in a generalized summary (Fig. 2) of the seasonal trends in settlement by all common species recorded at the three experimental stations. The seasonal sequence shown, which has been re-arranged for continuity, represents observations from February 1954 to January 1955.
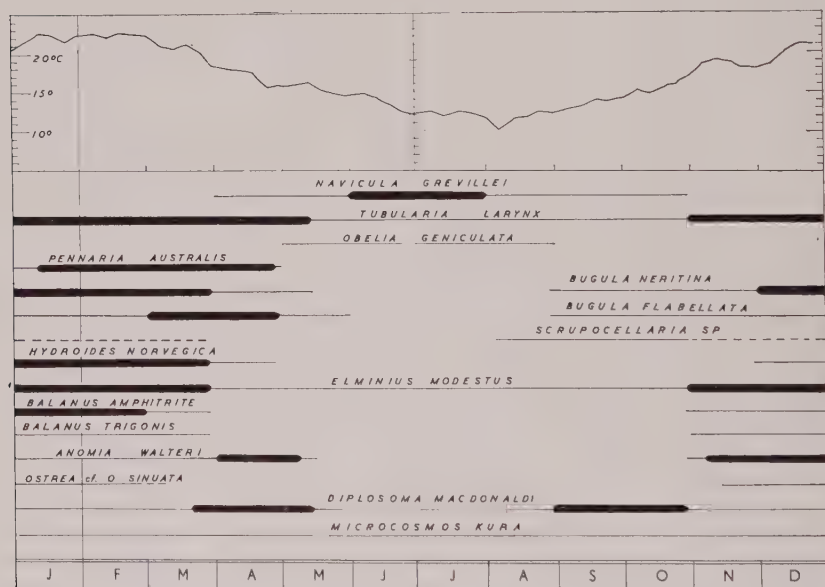

Fig. 2.—The annual record of settlement of fouling organisms at Auckland. Sea surface temperatures are plotted as means of six-day periods from Skerman, 1958a.

The Fouling Species

Algae

Navicula Grevillei

Between April and October, the characteristic mucous colonies of this diatom developed abundantly on one and two-month panels at A4, growth being most conspicuous on the north faces of these surfaces. A number of colonies were also found at A5 during this period, but none appeared at A1. Heaviest settlement at A4 took place in June and July, a time when attachment by other forms was much reduced. It is

possible that the establishment of *Navicula* on panels may have been restricted during the warmer months of the year, when colonization by more abundant species was at its greatest intensity, for colonies were uncommon on long-term panels bearing other heavy growth. The apparent period of *Navicula* settlement between April and October as defined by monthly panels may therefore have been shorter than, in fact, is the case; in Lyttelton Harbour (Skerman, 1958b), settlement was found to extend into the early summer, when sea temperatures averaged 20° C.

Hendey (1951) reported *Navicula Grevillei* as being one of the most important of fouling diatoms in Chichester Harbour, this species showing a strong resistance to copper oxide-containing antifouling paints. Here settlement was recorded during the winter at temperatures from 4° C to 7° C, and Hendey noted that colonies, which grew to a maximum of 12 cm in length, were seldom found below 15 cm from the surface of the water on experimental panels attached to floating rafts. In Auckland Harbour, *Navicula* colonies never exceeded 3 cm in length on test panels (in Lyttelton Harbour, 5 to 6 cm), but, as the position of these at all stages of the tidal cycle was deeper than 15 cm below the surface, optimal conditions for growth and development may not have been reached. This may also account for the weak persistence of *Navicula* colonies on long-term panels.

Hydroids

Tubularia larynx

With its ability to settle on surfaces throughout the whole year and its high rate of growth, this hydroid became one of the most conspicuous fouling species encountered in the harbour. The heaviest settlements that took place between November and mid-May commonly resulted in panel surfaces being completely obscured by *Tubularia* colonies, stems of which grew up to 2 in. in length within three weeks of settlement in the midsummer months. The species was more consistently represented on monthly panels at A5, but the most dense establishment of colonies occurred during the summer at A1 (Fig. 3). At A4, relatively light settlement prevailed, and here *Tubularia* appeared to be replaced by polyzoan populations (*Bugula neritina*) which flourished at this particular site.

The development of numerous epizoic *Tubularia* colonies upon the shells of closely packed barnacles was a notable feature during the summer months at A1. These dense hydroid populations were frequently accompanied by the accumulation of much mud and silt about the bases of the stems and over the summits of the barnacle shells, a factor which may have contributed to the high mortalities so frequently observed among young barnacle populations on A1 panels.

From its continuous and relatively abundant settlement throughout the year, it might have been expected that this hydroid would have been a dominant species on all panels, for, even if individual colonies were short-lived, newly attached actinulae might have led to their rapid

replacement. However, extensive *Tubularia* populations were, in general, limited to short-term panels, and the species was only of minor importance in association with fouling communities developing after three or more months. These differences appeared to arise from the selective nature of epizoic settlement by *Tubularia* which, on heavily populated surfaces, attached to the shells of barnacles, serpulids, molluscs (*Ostrea* and *Anomia*), but either failed to establish or avoided settlement on the tests of ascidians or amongst numerous polyzoan colonies. As ascidian communities generally dominated the surfaces of long-term panels, these settling characteristics may offer some explanation for the paucity of *Tubularia* upon them. At station A1, in contrast to A4 and A5, ascidians were slow to establish on certain long-term panels, and on these *Tubularia* persisted in great abundance.

FIG. 3.—Heavy *Tubularia* growth developing over basal *Elminius* and *Balanus* populations on a panel submerged two months (March–April) at Kauri Point.

Tubularia larynx is a very common fouling species, and has been recorded from test surfaces, buoys, wrecks, and ships in British waters (Woods Hole Oceanographic Institution, 1952; Pyefinch and Downing, 1949). Barnes (1948) showed that *Tubularia* is one of the fouling

organisms having a high resistance to copper poisons. Although the
species has been observed in Otago Harbour (Ralph, 1953) and in
Wellington Harbour (Ralph and Hurley, 1952), the present communi-
cation appears to be the first record of its presence in Auckland waters.

Pennaria australis

Except for the occasional appearance of colonies on panels at A5,
this species was confined to A1, where in both 1954 and 1955 settlement
took place between mid-January and April. Although not developing
with the same uniform density over panel surfaces as did *Tubularia*
colonies, the closely aggregated *Pennaria* colonies grew very rapidly
and in summer the thick black stems became prominent components of
fouling assemblages developing on all panels at A1 (see Fig. 8). Length
of the stems of largest colonies reached 5 cm after a maximum of one
month since settlement (March), 7 cm after two months (March to
April), and 9 cm after four months (February to May).

It was noted that *Pennaria* colonies grew in conspicuous abundance
on the surfaces of the brass frames holding the test panels, and on
the panels themselves settlement was greatest by the panel borders in
immediate proximity to the brass supporting-channels. Pyefinch and
Downing (1949) reported an experiment of which the results indicated
that the addition of small amounts of copper and mercury to sea water
stimulated the attachment of *Tubularia* larvae to surfaces. Similar
influences of metal ions may also have induced the heavy settling of
Pennaria on the brass surfaces, but there was no evidence to indicate
whether this or other biological or physical characteristics of the surfaces
were responsible.

?Obelia geniculata

In 1954, this hydroid was a dominant form on monthly panels set
from May until August. It settled less intensively in 1955, when it
was more prominent on long-term panels.

Polyzoa

Bugula neritina

Settlement of this species took place almost exclusively at A4, only
a few colonies arising at the other stations during periods of peak
settlement intensity. Larval colonization at A4 commenced in Septem-
ber and continued until June, with heaviest setting between December
and March. *Bugula neritina* was a common species at A4 on all surfaces
whose exposure period coincided with the season of settlement. On
monthly panels set in December, January, February, and March, small
colonies arose at a density of up to 30 per sq. decimetre; most panels
immersed three or more months at A4 outside the June–August period
bore large colonies up to 7·5 cm in height, with the result that *B. neritina*
was commonly a sub-dominant form on long-term panels.

An indication of growth rates is given in Table 1, which summarizes the maximum heights attained by colonies taken from different panels set at A4.

Table 1.—Growth of *Bugula neritina* Colonies at A4.

Immersion (weeks)	Period	Maximum height of colonies (cm)
4½	April–May	1·0
5	September–October	2·0
5½	March–April	2·5
7	November–December	1·5
8	March–April	2·6
10	November–January	6·0
16	September–December	7·5
19	February–January	7·0

In Lyttelton Harbour, larval settlement of the form *Bugula* sp. aff. *B. neritina* was found to take place between December and May (Skerman, 1958b). During the major part of this period, sea-surface temperatures exceeded 15° C, and it is of interest to note that settlement of *B. neritina* in Auckland also occurred when sea temperatures were above a similar level. This observation is comparable with overseas records of temperatures at which *B. neritina* commences larval settlement—viz., 15° C at Beaufort, North Carolina, 18° C at Kure Beach, N.C., 15° C at La Jolla, California, and 17° C at Kanazawa, Japan (Woods Hole Oceanographic Institution, 1952, p. 52). *Bugula neritina* is a very common fouling species with a wide geographical distribution (Woods Hole Oceanographic Institution, 1952).

Bugula flabellata

In several respects, the occurrence of this species paralleled that of *B. neritina*. It seldom appeared on surfaces at A1, larval settlement continued from September until the end of May, and it was a familiar form on many long-term panels. In contrast to *B. neritina*, it was more abundant at A5 than at A4, and during the period of most dense settlement in March and April, the numerous small colonies dominated the surfaces of 1- and 2-monthly panels at A5. This distribution is consistent with the observations of Allen and Wood (1950), who noted that in Australian waters *B. flabellata* was found in localities where hydrological conditions approximated those of the open sea. *B. flabellata* colonies, when fully grown, are not as large as those of *B. neritina*, as indicated in Table 2, which gives the maximum heights of colonies taken from various panels after different periods of immersion.

TABLE 2.—Growth of *Bugula flabellata* Colonies.

Immersion (weeks)	Period	Maximum height of colonies (cm)
4 (A4)	April	1·0
4 (A5)	April	1·5
4 (A5)	May	0·8
4 (A4)	September	0·8
7 (A4)	November–December	1·5
10 (A5)	November–January	2·2
10 (A5)	March–May	2·2
13 (A5)	August–October	2·2
15 (A5)	May–September	2·5
17 (A5)	May–October	2·5

Scrupocellaria sp.

This was a form which rarely colonized short-term panels, but the characteristic squat orange-coloured colonies were very common on surfaces immersed three months or more, particularly during the late winter and spring. *Scrupocellaria* sp. appeared at all stations, being most abundant at A1 and A4, where it became a dominant species on panels withdrawn between September and December after having been submerged throughout the preceding winter. Colonization of panels commenced in August and was at its peak intensity during September and October. Settlement probably continued throughout the summer until March, but owing to the irregular appearances of colonies on monthly panels set during the summer (possibly as a result of the high density of settlement by other more abundant species) this could only be inferred from the presence of older colonies on long-term panels.

Serpulids

Hydroides norvegica

Between early December and April, heavy settlement of this tubeworm took place on panels at A4 and A5. The calcareous tubes were familiar objects on all panels whose exposure period included the summer months and *Hydroides* individuals persisted on prolonged immersion even after panels had become dominated by heavy ascidian growth. The species was recorded only infrequently from panels at A1; this may have been a result of the heavier barnacle settlement prevailing at this site during the summer, for successful establishment of serpulids semed to be related to the amount of unoccupied surface available, for which *Hydroides* would have competed with the barnacles *Elminius* and *Balanus*. The tubes of young *Hydroides* were invariably fixed directly to the surfaces of panels; further growth of the tubes, when associated with heavy polyzoan and hydroid settlements, continued normal to the plane of the surfaces as previously observed in summer months at Lyttelton (Skerman, 1958b). Epizoic settlements of *Hydroides* were rare.

Information on growth of *H. norvegica* is summarized in Table 3. The size of measured individuals from various panels is given as the overall length of the calcareous tubes. As difficulty is experienced in measuring greatly coiled tubes, the figures given refer to the largest of relatively straight specimens.

Table 3.—Density of Settlement and Growth of *Hydroides norvegica*.

Immersion (weeks)	Period	Total No. individuals per sq dm	Tube length of largest individual (cm)
4 (A5)	January 1955	121	1·5
4 (A5)	February 1954	5	1·4
4 (A4)	February 1954	21	1·2
5 (A5)	March 1954	32	0·8
4 (A5)	April 1954	32	2·5
6 (A5)	March–April 1955	70	2·0
8 (A5)	March–April 1954	35	1·2
8 (A4)	January–February 1955	39	1·8
10 (A4)	March–May 1955	43	2·1
10 (A5)	March–May 1955	30	2·0

Hydroides norvegica is one of the most common of ship-fouling serpulids, having been reported from the Atlantic coast of Europe, the Mediterranean and Red seas, and from the Pacific Islands (Woods Hole Oceanographic Institution, 1952). Wood and Allen (1958) regard the species as the most important of ship-fouling organisms in New South Wales ports.

Galeolaria hystrix

This species was infrequently recorded from panels at A4 and A5 only. Settlement was noted on monthly panels in September, October, November, December, and in May, but the occurrence of individuals on certain long-term panels suggested that attachment also occurred between January and April. Individual tubes were small, usually under 2 cm in overall length, even on panels submerged six months. Growth appeared to be slow.

Mollusca

Anomia walteri

A species which was able to live in association with considerable masses of polyzoan and simple ascidian growth, this was a common form on many long-term panels. Attachment to surfaces took place between November and mid-May, being heaviest before January and after March. On monthly panels, *Anomia* settlement was common at A5, but most abundant at A4. Individuals were rarely found on these short-term surfaces at A1, but they did appear on panels immersed at

this site for longer periods. These features of the initial establishment of *Anomia* on panels at the different stations suggest an inverse relationship to the intensity of contemporary settling by barnacles, which was greatest at A1 and least at A4. As *Anomia* grew only on unoccupied areas of panels, individuals would have had to compete primarily with barnacles for free space. With the progressive reduction of pioneer barnacle populations on long-term panels during the summer, more suitable conditions for *Anomia* colonization, such as noted at A1, would have arisen.

GROWTH.—Table 4 summarizes information accumulated on the sizes of largest individuals taken from panels submerged for various periods. It should be noted that, as many fouling forms commonly covered *Anomia* populations on panels, there may have been some restricting effects on normal rates of growth.

TABLE 4.—Growth in *Anomia*.

Immersion (weeks)	Period	Largest size— length of left valve (mm)
4½ (A5)	April–May 1955	3·5
7 (A4)	November–December 1954	7·5
10 (A5)	March–May 1955	11·0
19 (A4)	February–June 1954	17·5
19 (A4)	February–June 1955	18·0
19 (A4)	October–February 1955	20·0
19 (A5)	February–June 1954	23·0
19 (A5)	February–June 1955	32·0
21½ (A5)	January–June 1954	22·0
26 (A5)	December–June 1955	24·0
26 (A4)	December–June 1955	35·0

Ostrea cf. *O. sinuata**

Settlement of this oyster was mainly confined to the stations A4 and A5. It appeared only on long-term panels (see Fig. 10), and careful searching for small individuals on monthly and two-monthly panels proved unsuccessful. The data are thus inadequate to define the season

*Dr C. A. Fleming, to whom all mollusc samples were referred, advises that the oysters could not be satisfactorily determined. Most of the specimens agree much better with the "Stewart Island" mud oyster, *Ostrea sinuata* Lamarck, than with the "Auckland" rock oyster, *Crassostrea glomerata,* mainly an intertidal form, but no authentic juveniles of the latter species are available for comparison with the juveniles in the samples. Dr Fleming notes further, "applying the criteria cited by Thomson (*Aust. J. Mar. Freshw. Res. 5*: 162–3, 1954), some of the specimens are recessed below the hinge (as in *Crassostrea*), but the muscle scar is central (as in *Ostrea*); the first character, however, is variable in *Ostrea*. The exterior of prismatic scales agrees with *O. sinuata*, as does the poverty of pigment, weakness or absence of marginal denticles, and of sculptural corrugations."

of settlement with any precision, but the presence of numerous small oysters on long-term panels withdrawn in the early summer indicated that spat commenced to settle about November and continued to do so at least until February. The apparent failure of *Ostrea* to colonize short-term panels at A4 and A5 as well as most panels at A1 may, as suggested in the case of *Anomia,* be a result of competition on these surfaces from barnacle populations which were either absent or greatly reduced on the 4- and 6-month panels on which *Ostrea* settlement and growth flourished. In the United Kingdom, *Elminius* has been observed to be a serious competitor of newly settled spat of *Ostrea edulis* (Knight-Jones and Stevenson, 1950), growth of the surviving oysters among the crowded barnacles being appreciably restricted (Knight-Jones, 1948).

Fig. 4.—Dense *Elminius* and *Balanus* settlement on a panel set at Kauri Point during December 1954. For illustration purposes, most of the epizoic *Tubularia* growth has been removed.

Other Molluscs

Four small mussels (*"Mytilus"* or) *Perna canaliculus* were found enmeshed amongst *Tubularia* stems on a panel immersed four months (July to October 1955) at A5. Measurements of the largest individual were: anterior-posterior, 3 mm; dorso-ventral, 6 mm; thickness, 3 mm.

A single individual of *Musculus impactus* was taken from a panel at A5 after six months (January to June 1955), its size being anterior-posterior, 10 mm; dorso-ventral, 12 mm; thickness, 8 mm.

Cirripedia

Elminius modestus

With larval settlement continuing throughout the whole year and a capacity for dense colonization of newly set panels at all sites, *Elminius modestus* ranked as a fouling species of prime importance. Panels immersed as little as three weeks in midsummer bore many hundreds of young *Elminius* barnacles, and growth of these populations soon led
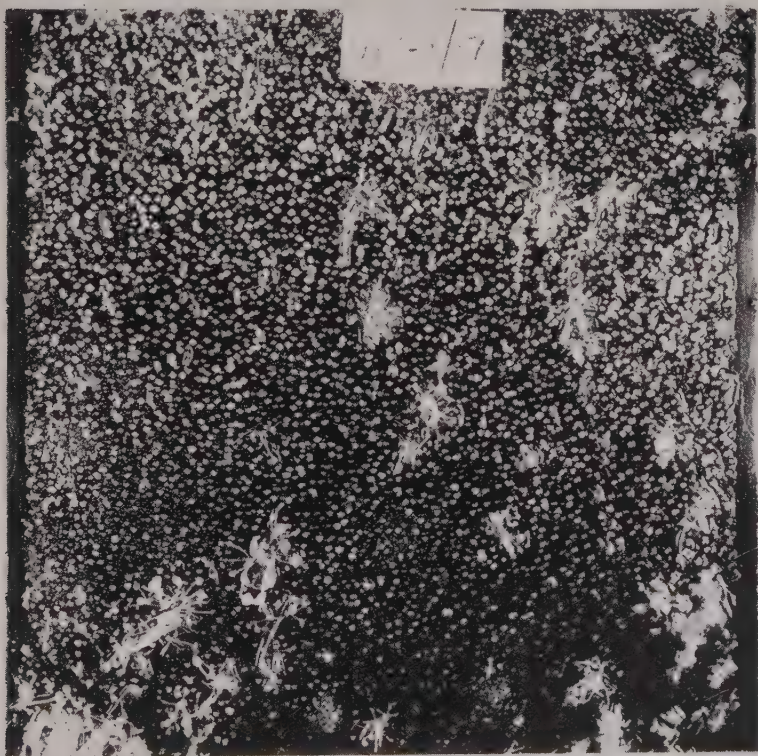
Fig. 5.—Winter settlement of *Elminius* and *Tubularia* at North Head. Panel submerged during July 1954.

to the surfaces being completely covered by a mass of closely packed shells (Fig. 4). Settlement was generally lighter during the winter, but heavy sets of up to 1,870 barnacles per sq. decimetre were occasionally observed on monthly panels at A5 (Fig. 5). Of the three species of barnacles recorded from test panels, *Elminius* was numerically the most abundant, except on certain monthly panels at A1, where *Balanus amphitrite* settlement was particularly heavy.

During the summer, when intensive *Elminius* and *Tubularia* colonization of newly set panels took place, it was repeatedly observed that, whereas the barnacles attached directly to the surfaces of panels, *Tubularia* colonies arose from settlements primarily upon the barnacle shells. Under these circumstances, secondary settlements of young barnacles upon the shells of pioneer populations were rare, and the epizoic relationship was dominated by *Tubularia*. This characteristic relationship may have exerted some control over the survival of the barnacle populations, for on monthly panels at A1 where exceptionally heavy *Tubularia* growth
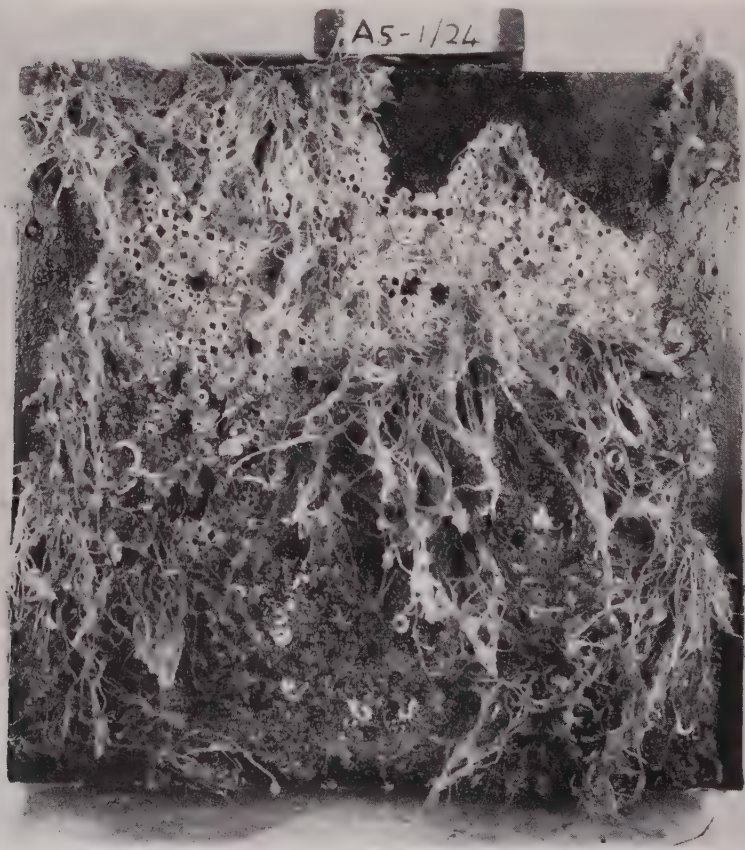

FIG. 6.—Mortality in *Elminius* populations under heavy *Tubularia* settlement (partly removed) after one month's submergence at North Head.

developed (see Fig. 3) high mortalities of 50% to 60% among the underlying barnacles were commonly observed in summer (cf. Fig. 6). Higher mortalities, above 70%, were recorded from two monthly panels. As the development of dense stands of *Tubularia* at A1 was also accompanied by an accumulation of much mud and silt which formed a thin blanket over the barnacle populations, the establishment of *Tubularia* at this site may have been a factor contributing only indirectly to mortalities in the underlying barnacle populations.

The numbers of *E. modestus* settling on short-term panels at each station between February 1954 and October 1955 are plotted in Fig. 7.
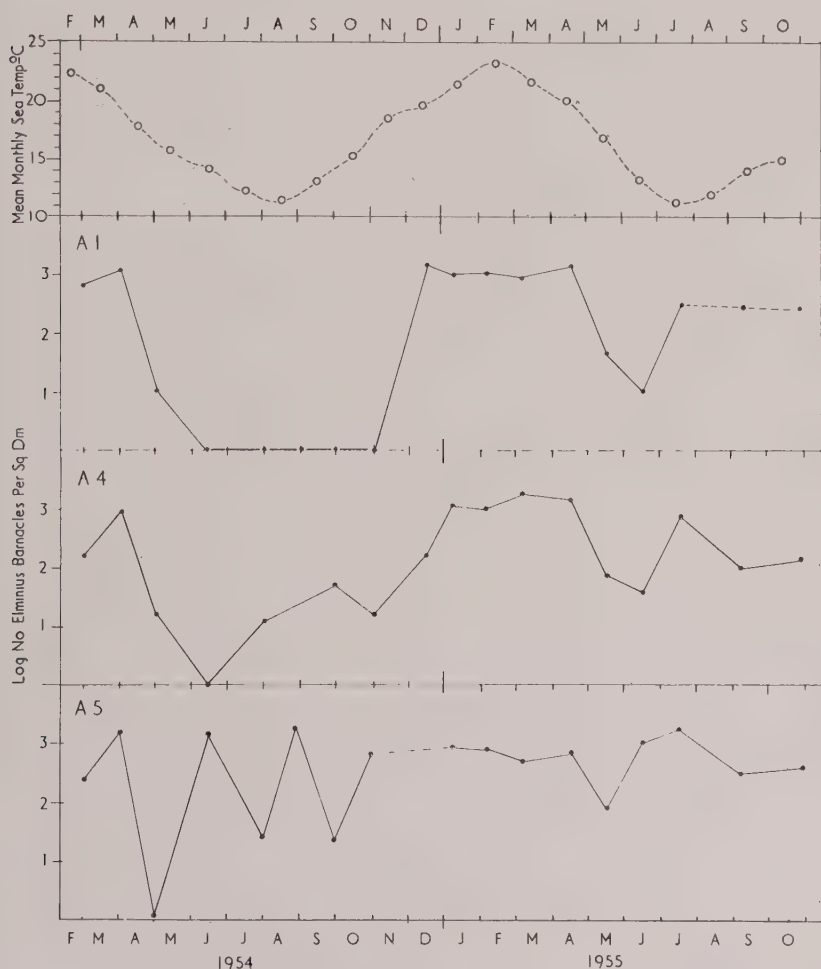
FIG. 7.—Monthly settlement of *Elminius modestus* from February 1954 to October 1955 at the three sites. Sea-surface temperatures plotted as monthly means from Skerman, 1958a.

It can be seen that, from December to April, settlement intensity remained at a fairly consistent high level at all stations, whereas wide fluctuations occurred from month to month at other times of the year. Throughout the whole period, numbers of *Elminius* attaching to panels at A5 were, on the whole, higher and less variable than at A1 and A4. No barnacles settled at A1 between June and October in 1954, a feature which did not recur in the following winter. Common to all stations was a marked falling-off in settlement about the end of April 1954. Though less pronounced, this was repeated in 1955.

Growth.—There was a considerable variation in the shape of individual *Elminius* shells according to circumstances in which they were growing. In crowded assemblies, shells tended to be tall and sub-cylindrical, with walls only slightly folded longitudinally, whereas isolated barnacles were generally conical, depressed, and often with walls deeply folded. These characteristics introduced a difficulty in compiling data on growth rates using basal diameter as a size index. At A4, however, *Elminius* settlement was relatively lighter than at the other two sites, and it was possible to select for measurement more isolated individuals whose shell growth on panels was less likely to have been restricted under crowded conditions. The details are summarized in Table 5.

Table 5.—Sizes of the Largest *Elminius modestus* Barnacles
on Panels at A4 after Differing Periods of Immersion.

Immersion	Period	Largest size— rostro-carinal diameter (mm)
1 month	January 1955	4·4
	February 1955	5·0
	March 1954	4·2
	March 1955	4·0
	April 1955	3·8
	May 1954	2·5
	May 1955	1·3
	June 1955	1·8
	July 1954	2·0
	July 1955	2·5
	September 1954	3·2
	December 1954	4·4
2 months	December–January 1954	5·2
	December–January 1955	4·2
	January–February 1955	5·7
	April–May 1955	7·0
	June–July 1954	3·0
	June–July 1955	4·4
	September–October 1954	4·9
4 months	March–June 1955	8·6
	July–October 1955	10·5

These data suffer from the obvious disadvantage that the period of immersion of a panel does not necessarily represent the total time elapsed since settlement of the largest barnacles it carrries. In general terms, however, there is a strong indication of a seasonal variation in growth rate during the first month after settlement, and it appears that the rate of growth during this period may be almost twice as great as that observed in the port of Lyttelton (cf. Skerman, 1958b, p. 242).

Balanus amphitrite var. *cirratus*

Unlike *Elminius,* settlement of this barnacle on test panels was limited to the period between November and March. It occurred chiefly at A1, settlement at A4 and A5 being less regular and individuals fewer in number. During the warmest months of January and February, panels set at A1 were dominated by *Balanus amphitrite,* whose large shells, together with those of *Elminius,* formed thick basal encrustations over the surfaces. As noted earlier, numerous *Tubularia* and *Pennaria* colonies grew over these barnacle populations.

Despite the large numbers of *B. amphitrite* attaching to monthly panels at A1, relatively few individuals were found to survive on surfaces immersed for longer periods, with the result that empty shells devoid of opercular valves were a conspicuous feature of panels withdrawn two, four, or six months after the summer period of settlement. As suggested in the case of *Elminius,* this mortality may have resulted from the dense overgrowth of barnacles by hydroids and the attendant silting up of panels observed at this site, but there was some evidence suggesting that another factor may have affected the survival of young *Balanus* populations. Between November and March, numerous small polyclad turbellarians were seen on monthly and two-monthly panels set at A1, and, while some of these individuals could be observed roving freely over the crests of barnacle shells, other flatworms were found with their bodies projecting partly through the opercular apertures. Many barnacle shells, in which opercular plates were apparently intact, showed, on removal from the panels, the interior spaces to be fully occupied by single flatworms, with little evidence of any remaining barnacle tissue. Closer examination of the evidence is required to establish the nature of this relationship between the polyclad (as yet unidentified) and the barnacle populations, but if it is one involving active predation of the young barnacles, the high incidence of polyclad-invaded barnacle shells on short-term panels indicates the importance of the association in the survival of barnacle populations. Polyclads were also found within the smaller shells of *Elminius,* but they were more common in those of *Balanus.* They rarely occurred on panels at A4 and A5, and thus both their seasonal and locational appearance closely paralleled those of *Balanus amphitrite.*

GROWTH.—*Balanus amphitrite* grew rapidly. Due to the severe crowding on panels at A1, and consequent irregularities in the shape of individual shells, valid data concerning the sizes of shells after various intervals of time since settlement were difficult to secure. Table 6

summarizes available information on growth based on measurements of the largest barnacles selected from least crowded areas of panel surfaces at A1.

Table 6—Growth in *Balanus amphitrite* var. *cirratus*.

Immersion (weeks)	Period	Largest size— rostro-carinal diameter (mm)
4	January	10·0
4	February	11·3
5	March	9·5
5½	March–April	9·5
7	November–December	12·0
9	February–April	12·5
9	January–March	15·0
10	November–January	13·5
10	March–May	20·0

As so few *B. amphitrite* survived more than a month after settlement, no reliable data are available on the size or age of individuals at maturity. The smallest specimen bearing nauplii in the mantle cavity was taken from a two-month panel and had a basal shell diameter of 14·0 mm. This size was reached by individuals in a little more than a month after settlement in midsummer, and it is likely that release of nauplii occurred within at least two months. Paul (1942) recorded *B. amphitrite* individuals attaining maturity 16 days after settlement (8·8 mm in size) at Madras, India.

Allen and Wood (1950) found *Balanus amphitrite* var. *cirratus* to be a common barnacle settling on test panels on the East Australian coast between Eden and Moreton Bay; they recorded specimens measuring 9 mm in basal diameter within a period of four weeks of settlement at Sydney. The same authors (1958) stated that both the varieties *communis* and *cirratus* of *B. amphitrite* live under a wide range of salinity conditions and may be found in brackish waters of estuaries.

Balanus trigonis

This species appeared at all stations. On short-term panels, numbers were never as great as those of either *Elminius* or *Balanus amphitrite*, but, in showing a tendency to survive longer in association with other fouling forms, *B. trigonis* commonly became the dominant barnacle found on long-term panels. Settlement took place from November to March, being heaviest at A4, lightest at A1. Growth after settlement was notably slower than in *B. amphitrite*, largest individuals reaching 4·8 mm in rostro-carinal diameter after a maximum of 3 weeks, 6 mm after 8 weeks, 8·8 mm after 14 weeks, and 16·0 mm after 26 weeks. Turbellarian invasion of shells was also noted in *B. trigonis* populations, but the incidence was much lower than in *B. amphitrite*.

Ascidians

Corella eumyota

This simple ascidian settled in every month between November and July at both A4 and A5, heaviest settlement taking place in March and April. It was found chiefly on monthly panels, prolonged immersion of surfaces usually resulting in the replacement of *Corella* by *Asterocarpa* and *Microcosmos*.

Asterocarpa cerea

Sporadic settlement on monthly panels by this species was recorded throughout the year. Greater numbers of individuals were present on surfaces immersed for longer periods, and *Asterocarpa* became a dominant species of certain 4-month panels. Dominance on these surfaces, however, was usually short-lived, and the *Asterocarpa* populations tended to be ultimately succeeded by *Microcosmos*.

Microcosmos kura

With a few exceptions from A1, this simple ascidian was represented on all panels withdrawn after four and six months' immersion. At A4 and A5, thick clumps consisting of many closely-packed individuals developed on these surfaces, with the result that *M. kura* commonly became the dominant species of long-term fouling associations (see Fig. 9). In no instance was the species recognized on monthly and two-monthly panels; however, its unfailing presence on four-monthly panels at A4 and A5 withdrawn in September, January, and May was a strong indication that settlement took place throughout the year.

Styela plicata

Although settling at all stations, *Styela* was not a common ascidian on test panels. It attached to monthly panels between January and April, and on some 4- and 6-monthly panels whose period of immersion included these summer months.

Botryllus schlosseri

This was the rarest of compound ascidians developing on test panels, only a few colonies appearing during March of each year at A4.

Diplosoma macdonaldi

Diplosoma colonies developed abundantly on many panels during the whole year. While it appeared at all stations, the most extensive settlement and growth occurred at A4, where, within a month of initial establishment on surfaces, spreading colonies up to 40 sq.cm in area were observed during the autumn and spring periods of peak settlement.

Botrylloides leachi

A few colonies only were noted from a single panel immersed six months (January to June) at A4.

Aplidium (Amaroucium) phortax

This compound ascidian was found on two panels withdrawn at A4 and A5 in May, 1954, after six months' immersion. Closely settled *Microcosmos* populations growing on these panels were partially enveloped by gelatinous masses of the *Aplidium* tests. This form was not seen on short-term panels, nor did it develop on similar 6-monthly panels set during the following year.

Fouling Developed on Prolonged Immersion of Panels

Progressive changes in the composition of communities of fouling organisms were shown by panels submerged for four- and six-monthly periods. Care was required in interpreting the data from these surfaces, some of which showed evidence of having lost some of the typically heavy growth developed over this length of time. There was, however, a good overall correspondence between similar series of panels in both years.

Panels Submerged Four Months

February to June.—The massive growth developed over this period at A1 consisted largely of closely settled *Pennaria* and *Tubularia* colonies (Fig. 8), which overlay thick encrustations of *Balanus amphitrite* and *Elminius* shells, less than 10% of which were those of live animals. A few *Anomia* were present on the 1954 panel, and isolated *Microcosmos* individuals had established in 1955. Areas where growth had stripped off had been recolonized by *Elminius* and *Tubularia*. Large *Bugula neritina* colonies dominated the less heavily settled panel at A4, on which most forms settling during the intervening months were represented. The moderate *Elminius* population present, in contrast to that at A1, consisted of live animals which shared space on panel surfaces with the tubes of numerous *Hydroides*. No *Balanus* were present. Many small *Anomia* and several *Ostrea* were present in both years, as well as moderately dense strands of *?Obelia*. Ascidian components comprised a few *Corella, Diplosoma,* and a small number of *Microcosmos*. At A5, surfaces were dominated by the hydroid *?Obelia* in 1954, and by colonies of *Bugula neritina* in 1955. Many *Anomia* were attached to panel surfaces as well as the serpulid *Hydroides,* but, curiously, only odd *Elminius* were present despite the heavy set of this barnacle which took place on adjacent monthly panels in February, March, and May of both years. Much of the surface was occupied by *Diplosoma* colonies, a possible source of detraction to settlement by barnacles, and some large *Microcosmos* individuals were prominent in both years.

Unlike those at A1, panels at A4 and A5 carried only the remnants of earlier extensive *Tubularia* populations.

Fig. 8.—A typical hydroid (*Pennaria* and *Tubularia*) dominated community developing after four months (February to May) at Kauri Point. Compare with Fig. 9.

JUNE TO SEPTEMBER.—Panels submerged at A1 over this period did not carry much growth. *Elminius* populations, in which almost no mortality was observed, dominated the surfaces, and light settlements of *Tubularia* and *Scrupocellaria* arose in both years.

Elminius were also abundant on panels from A4, but heavy growth by *Asterocarpa* and *Microcosmos* here led to ascidian-dominated communities. Numerous *Scrupocellaria* colonies were prominent, and in

1955 some large colonies of *Bugula neritina*. Other species included *?Obelia*, several *Galeolaria* tubes, and some large spreading colonies of *Diplosoma*. The northern faces of panels bore isolated *Navicula* colonies.

Fouling assemblages of a similar composition developed at A5, where, however, the dominant ascidian growth was much heavier and consisted solely of *Microcosmos*. The many *Tubularia* stems devoid of terminal hydranths were evidence of earlier dense settlement by this hydroid, and a few *Bugula flabellata* colonies grew epizoically upon the basal *Elminius* barnacles. A few small *Galeolaria* tubeworms survived among the barnacle settlements, and, as at A4, some *Navicula* colonies flourished on the north faces of panels.

OCTOBER TO JANUARY.—Fouling communities developed over this period at A1 greatly resembled those borne by the panels set between February and June, except for the lighter growth of *Pennaria*, a form which only commenced settlement in January. Thick barnacle encrustations of both *Balanus amphitrite* and *Elminius* consisted mainly of empty shells, and turbellarian invasion was widespread. Heavy *Tubularia* growth covered the barnacle shells, among which grew a number of small *Ostrea*.

The ascidian *Microcosmos* dominated on panels at A4. Moderately dense barnacle settlements underlying the ascidians were exclusively *Balanus trigonis*, and other forms attached directly to the panel surfaces were many *Hydroides* tubeworms, a number of large *Anomia*, and a few small oysters. Several large *Bugula neritina* colonies were probably the survivors of more extensive polyzoan populations previously lost from the panels. *Diplosoma* growth was extensive.

Similar *Microcosmos*-dominated communities to those at A4 developed at A5, with the notable exceptions that only a few barnacles (*Elminius*) were present and several *Tubularia* colonies were interspersed among those of *Bugula neritina*. *Anomia* and *Hydroides* were also common, and *Ostrea* was represented by several clusters of large (*c.* 26·0 mm) shells and many small, more recently settled individuals.

Panels Submerged for Six Months

JANUARY TO JUNE.—There was a closer correspondence between fouling populations developing over this period at the three stations than in the four-monthly series. All surfaces were dominated by massive clumps of *Microcosmos*, among which large *Ostrea* shells were prominent (Figs 9 and 10). Beneath the ascidians and on less heavily populated areas of the panel surfaces were *Anomia, Balanus trigonis, Hydroides,* and a few scattered *Elminius*. Subordinate species whose presence distinguished panels from each of the sites were *Pennaria* at A1, *Bugula neritina* at A4, and *Tubularia* at A5. In 1954, the colonial ascidian *Aplidium* (*Amaroucium*) *phortax* grew over the *Microcosmos* clumps at A4 and A5, but this species did not reappear in the following year.

JUNE TO DECEMBER.—Communities on panels from A4 and A5 at the end of this period showed much resemblance in their constitution, both to each other and to those arising in the previous six monhs. Surfaces were again dominated by *Microcosmos*, among which grew many small *Ostrea* and *Hydroides*. Numerous colonies of *Scrupocellaria* and a few of *Bugula neritina* at A4, and the presence of a few *Tubularia* colonies at A5 were the only elements differentiating between panels from either station. In both locations, the scattered barnacle populations beneath the ascidians consisted exclusively of *Elminius*. At A1, because no ascidians were present, surfaces being dominated by heavy *Tubularia* growth, there was little superficial resemblance between these panels and those of A4 and A5. Subordinate components of the populations were, however, similar, consisting of *Anomia, Scrupocellaria,* and many small *Ostrea* and light settlements of *Balanus amphitrite* and *Elminius*.

FIG. 9.—A *Microcosmos–Ostrea* dominant association typical of communities developing after four and six months' immersion at Calliope Wharf and North Head.

Panels Submerged Twelve Months

MAY 1954 TO MAY 1955.—It was evident that some of the heavy fouling growth, probably ascidian, acquired by these panels had stripped off during later stages of the immersion period, "bare" areas having been recolonized by barnacles, hydroids, and serpulids. But as all panels bore many *Ostrea* and clusters of *Microcosmos,* it seemed that, as on six-monthly panels, these had been the dominant species at the time loss of growth occurred.

Despite some individual variation between sites, a number of general trends were evident in the development of these fouling communities on panels after extended periods of immersion.

(1) Fouling populations on many 4- and 6-month panels at all sites tended to resemble one another in their constitution in that they generally became dominated by ascidians, particularly the form *Microcosmos kura.*

(2) Species such as *Elminius* and *Tubularia,* that were prominent in the initial colonization of panels did not persist indefinitely; they were ultimately replaced as dominants by ascidian communities.

(3) The initial colonizing species, in particular barnacles and *Tubularia,* but also serpulids and *Anomia,* did not normally re-establish on surfaces after they had been superseded by ascidians.

(4) The oyster *Ostrea* cf. *O. sinuata,* which appears to have been unsuccessful in settling on short-term panels, established itself abundantly on 4- and 6-month panels in association with the *Microcosmos* populations.

(5) In that no other species rapidly replaced *Microcosmos* and *Ostrea* on long-term panels, the association formed by these two species achieved some stability under the experimental conditions for at least 12 months after initial immersion of the panels.

The form of this general sequence in the replacement of dominant species on panels may be a function of the differing capacities of species to become established on various types of surface, intensity of settlement and growth rate being of lesser importance. In the primary colonization of a newly immersed panel by barnacles and *Tubularia,* barnacles settled on the immediate surfaces, while *Tubularia,* possibly through an inability to compete with barnacles for free surfaces, established as epizoites on the barnacle shells. In the summer, the numerous *Tubularia* colonies arising, with an extensive development of stolonial systems, in turn appeared to prevent any secondary settlements by barnacles on the shells of the pioneer barnacle populations of which a large proportion of individuals failed to survive. In more advanced stages of the fouling history of panels, it was common to find other species, varying according to site and season, temporarily dominating the surfaces, but, during this time compound, and later, simple ascidians gradually gained ascendancy over the existing communities. Although

Fig. 10.—*Ostrea* settlement on a long-term panel. The same panel as shown in Fig. 9 after removal of the ascidians. To increase the contrast for illustrative purposes, the darker coloured right (upper) valve has been removed from each oyster.

many forms, including the scattered barnacles remaining on long-term panels, appeared to survive beneath the overlying ascidians, none of the common fouling species was able to establish itself successfully upon the tests of young ascidians, whose further growth would therefore have been virtually unrestricted by competing forms. There are no obvious reasons why *Microcosmos* ultimately became the dominant species of long-term panels. Earlier observations (Ralph and Hurley, 1952; Skerman, 1958b) have shown a tendency for *Asterocarpa cerea* to replace *Corella eumyota* on the prolonged immersion of test surfaces. Although neither of these species was common on Auckland panels, the same trend was apparent, but both species were eventually superseded by *Microcosmos*. In her type description, Brewin (1948) noted that, in the Hauraki Gulf, specimens occasionally grew singly, but more

often they were found in clumps together with *Pyura subuculata* and *P. rugata*. Such a "colonial" habit, possibly resulting from aggregational tendencies in larval settlement, might account for the clusters of closely packed individuals characteristically found on long-immersed panels.

Some departure from this general sequence of species replacement on long-term panels occurred at A1, where ascidians either were slow or failed to establish. Under these circumstances, there arose an extension of the phase of hydroid settlement, with the result that, even after six months' immersion, panels, like that shown in Fig. 8, were often still dominated by dense masses of *Tubularia* (and, in the summer, *Pennaria*) which overlay the empty shells of the pioneer barnacle populations. Once ascidians had settled, the usual sequence leading to *Microcosmos*-dominated communities was observed. As some settlement by oysters occasionally took place on long-term panels at A1 in the absence of *Microcosmos*, it is unlikely that any inter-specific factor induced *Ostrea* settlement among *Microcosmos* in the typical association arising on long-term surfaces at A4 and A5. Some influences on oyster settlement will be discussed later.

Most of the species conspicuous in the development of fouling communities on long-term panels are capable of settlement at any time of the year, and for this reason there were few marked seasonal differences in the developmental sequence. *Ostrea*, however, appeared to settle only during the summer, and it may have been possible to have had a long-term panel submerged for six months (for instance, June to October) without this form appearing. The evidence of the 12-monthly panels suggests, however, that, on continued immersion of such a panel, oysters would have subsequently become established in the summer, eventually leading to the characteristic *Microcosmos-Ostrea* association.

During the winter, when primary settlement by *Elminius* and *Tubularia* was less intensive, there was a wider representation of "subordinate" species, which had the effect of prolonging intermediate stages in the sequence prior to the dominance of ascidians.

Differences in Fouling between Sites

In the overall represenation of species on test panels throughout the experimental series, there was a closer resemblance between A4 and A5 than between either of these sites and A1. Settlement recorded at A1 was characterized by exceedingly heavy colonization by *Elminius*, *Balanus amphitrite*, *Tubularia*, and *Pennaria* in the summer, a low incidence of polyzoans, ascidians, and serpulids, the appearance of a few *Ostrea* and *Anomia*, and the absence of *Navicula*. At A4, there was comparatively lighter settlement by barnacles and *Tubularia*, with *Pennaria* not appearing on any occasion. The barnacle *Balanus trigonis* and the serpulid *Hydroides* settled in greatest numbers at this site, where the incidence of the polyzoans *Bugula neritina* and *Scrupocellaria* sp.

was also highest. Nearly all species recorded in the experimental series were found at A5, where the main distinguishing characteristics lay in the relatively high rate of *Elminius* and *Tubularia* settlement which persisted during the winter.

The lack of hydrological information precludes any discussion of the influences certain physico-chemical entities may have had upon these qualitative differences in fouling between sites. Being located farthest from the harbour mouth, the site A1 is probably subject to more variable estuarine conditions. The experimental panels at all stations were similarly placed with respect to depth and orientation, and exposure to the effects of prevailing winds is believed to have been comparable at the three sites, but, as noted earlier, tidal currents at A1 may have been weaker at A4 and A5. There was a tendency for panels at A1, even after they had acquired only a little fouling growth, to accumulate much silt and fine detrital matter which may have had important effects on the settlement or survival of some organisms.

The proximity to populations of numerous mature colonies is likely to have been a major factor leading to the high incidence of *Bugula neritina* settlement characteristic of panels set at A4. Calliope Wharf, on which this experimental station was located, forms the southern boundary of the partially enclosed wharf basin of the Devonport Naval Base. In addition to providing temporary berthage for naval vessels in commission, this area is also the permanent mooring site of a number of vessels maintained in reserve. Although the reserve ships are periodically docked for cleaning and repainting, the evidence indicates that the time interval between successive dockings exceeds the effective life of anti-fouling paints used. One of the most conspicuously abundant fouling species observed on these vessels is *Bugula neritina*, and large colonies have been seen on all but the most recently docked ships moored in the basin at all times of the year. Since *Bugula* larvae are known to settle within a few hours after they have been liberated from mature colonies (Miller *et al.*, 1948), these populations could have been a primary source of larvae ultimately colonizing the panels at A4. As the basin is sheltered from the major tidal currents arising in the Harbour, newly released larvae may not be dispersed very far from the immediate neighbourhood of the parent *Bugula* populations before settlement takes place; this may lead to a high degree of repopulation within a locality of primary larval dispersal.

Experiments made by Pyefinch and Downing (1949) showed that the exposure of actinula larvae of *Tubularia* to hypotonic sea water accelerated their attachment to surfaces, and it is possible that lower salinities of waters in the vicinity of A1 may have had a similar effect in promoting the heavy *Tubularia* settlements observed on panels in summer at this site. Other observations (Woods Hole Oceanographic Institution, 1952) indicate that *Tubularia* populations grow exceptionally abundantly in regions where swift currents prevail. Such conditions as these would have been met at station A5, where *Tubularia* settlement continued throughout the year.

Discussion

As would be expected in a region where marked seasonal changes in sea temperature occur, the high rates of settlement and growth of fouling organisms in summer months were appreciably reduced on surfaces exposed in harbour waters during the winter. Nevertheless, in Auckland Harbour, the species that were most prominent in winter settlement (e.g., *Elminius* and *Tubularia*) are common ship-fouling forms which reproduce throughout the whole year; qualitatively, therefore, winter fouling remains a matter of practical significance.

In relating the data from the experimental series of panels to the ship-fouling problem, the species of greatest importance will be drawn largely from the primary colonizers of newly immersed surfaces rather than from those forms appearing only in advanced stages in the development of more permanent communities on panels of which immersion has been prolonged. The evidence suggests that some exceptions to this generalization may arise in the cases of those species (e.g., *Ostrea*, *Scrupocellaria*) which do not readily colonize newly immersed panels; these instances emphasize the value of running series of short- and long-term experiments in parallel. Is is also probable that some of the interactions between species taking place under the competitive conditions on test panels may not be duplicated on the underwater surfaces of ships, and species of which settlement and growth are restricted on experimental surfaces may be much more liberally distributed in practice. For instance, the serpulid *Hydroides norvegica,* which has been observed to be responsible for heavy fouling of shipping in Auckland Harbour, did not become established in as great abundance on test panels where it may have frequently met with much competition from barnacles. Also, the factors which have been considered as contributing to the severe depletion of pioneer barnacle populations on panels in summer (p. 75) may not arise in conjunction with barnacle fouling on ships' hulls. These examples illustrate the necessity of appreciating the nature of these inter-specific reactions in applying the information provided by experimentl surfaces.

The failure of *Ostrea* to settle on monthly panels leaves the duration of the season of oyster settlemen in some doubt. This is unfortunate, for the species appears to be prominent among ship-fouling organisms in the harbour, and it would have been desirable to have had more accurate information on this matter. It has been suggested earlier that strong competition from the dense barnacle populations may have effectively prevented successful *Ostrea* establishment on the short-term panels in summer. Some further points concerning the abundant oyster settlement on long-term panels, typically dominated by the simple ascidian *Microcosmos* (see Figs 9–10) will now be considered.

(1) It is generally known that shelter from currents greatly influences the intensity of oyster setting. Korringa (1952), for instance, deduced that most of the setting of larvae of *Ostrea edulis* in the Oosterschelde was concentrated in the periods of slack

water. A demand for shelter in successful larval settlement and metamorphis on long-term panels may have been met by the presence of *Microcosmos* clumps which may have shielded spat settling among them from strong tidal currents.

(2) Cole and Knight-Jones (1949) considered that larvae of the oyster *Ostrea edulis* are gregarious in settlement, for experiments demonstrated that several times as many larvae attached to surfaces which already bore recently settled spat than to similar surfaces from which all previously settled spat had been removed. Similar larval behaviour in the present case may help to explain the abundance of young oysters on long-term panels carrying a few older large individuals.

(3) The apparent delay in oyster colonization of test panels until ascidian communities had developed does not seem to be paralleled in instances of *Ostrea* fouling of ships' hulls. Many vessels either based or regularly trading from the Port of Auckland have been found at docking to carry extensive *Ostrea* settlements in exposed situations on the under-water surfaces. In the majority of these cases, few other organisms are present adjacent to the young oysters, and generally there is little physical resemblance between the surfaces colonized on ships and those of long-term experimental panels bearing heavy ascidian growth that might explain the facility with which oysters settled on the two apparently differing types of surface. Although it is likely that ships berthed at wharves are sheltered from extreme tidal currents so that similar conditions prevail about the under-water surfaces to those on fouled test panels, the observations introduce matters concerning other characteristics of the settled surfaces. For any fouling organism to become established upon the surfaces of a ship's hull, it must be assumed that the residual toxicity of the anti-fouling paint used has fallen at least to a level which is below the maximum tolerance limit for settlement, normal metamorphosis, and growth. Thus, in some of the instances observed, it is possible that oysters may have settled on ships at a time when significant, though sub-lethal, amounts of toxic copper compounds were being leached from the paint surfaces. The literature contains a number of conflicting opinions on the effect of heavy metals on the settlement and metamorphosis of oysters. Prytherch (1934), for instance, considered that copper induced metamorphosis of larvae of the oyster *Ostrea virginica,* but some of his conclusions were criticized by Korringa (1940), and Lynch (1958) notes that the effect reported has not been confirmed by others. On the other hand, MacGinitie and MacGinitie (1949) claimed that oyster larvae could be made to metamorphose and settle by the introduction of small amounts of copper into the water in which they were living. They suggested that, as river water contains a slightly higher percentage of copper than does sea water (in the estuary of the Mississippi River, Riley, 1937–38, found greater amounts of copper in surface waters of lower salinity than in deeper waters where salinity was higher),

oyster larvae are stimulated to settle in bays and estuaries containing diluted sea water. Riley also showed that copper is readily absorbed by organic detritus, a feature which was later confirmed in intensive studies of the characteristics of primary slime films developing on various types of submerged surfaces (Woods Hole Oceanographic Institution, 1952). In these it was demonstrated that slime films arising on the surfaces of anti-fouling paints containing copper compounds as the toxic ingredients soon acquired a concentration of copper many times that of a saturated solution in sea water. Further, when a slime film formed on a non-toxic panel was placed in sea water containing copper, it was found that the metal was rapidly removed from solution and concentrated in the slime.

Experimental panels on which oysters settled in Auckland Harbour all carried films of a muddy nature in between the clumps of *Microcosmos,* and it was necessary to wash this material away to show the presence of the young live oysters (see Fig. 10). As heavily silted surfaces are generally considered to be most unfavourable for oyster settlement and growth (see, for instance, Korringa, 1952), these observations were surprising, but it is probable that only a small proportion of these numerous individuals would have survived prolonged immersion of the panels. In view of the findings of previous authors, it is likely that the films would have accumulated copper not only from sea water but also from copper corrosion products on the brass frames holding the panels. No analyses of films were made in the present investigation to test this possibility, neither have any experimental studies been carried out to determine whether there is a demand for copper at the time of setting or metamorphosis in *Ostrea sinuata*; the above considerations, therefore, only point out the possibilities of a resemblance in chemical properties between abundantly settled surfaces of apparently dissimilar types. Critical investigation is required to establish the effects, if any, of such properties on oyster settlement and their importance in relation to the more widely understood factors such as shelter of surfaces from strong tidal currents and their freedom from heavy sedimentation.

An important result of world-wide systematic fouling studies is a knowledge of the intensity of fouling which prevails at any port. Yet there are few suitable quantitative criteria that may be applied in any comparison of fouling intensity between different ports or regions. Figures based on the weights or volumes of fouling growth acquired by test surfaces of a given area per unit time of immersion tend to be misleading because of the diversity of organisms concerned. Probably more satisfactory characteristics for comparison are the length of seasons of attachment, densities of settlement, and growth rates of those species known to be important ship-fouling types. When this information is based on the data of test panels, however, minor year-to-year variations in seasonal attachment, fluctuations in settlement density, and other differences arising between sites and depths of

experimental immersions within the same port must be taken into account. Of the 25 species recorded from test surfaces in Auckland Harbour, 15 are known to foul ships' hulls, the most commonly represented being *Tubularia larynx, Pennaria australis, Bugula neritina, B. flabellata, Hydroides norvegica, Ostrea* sp., *Elminius modestus,* and *Balanus amphitrite* var. *cirratus.* The dense settling of nearly all these forms on test panels within a comparatively short time of immersion during the period between November and March–April is indicative of a high fouling intensity that prevails for almost six months of the year.

In addition to the broader influences of temperature and salinity on the geographical distribution of fouling organisms, other local factors may have had supplemental effects on the intensity of fouling. Organic material introduced into Auckland Harbour waters in the discharge of domestic sewage (Wallace *et al.,* 1953a, 1953b, 1958) may constitute an important food supply for fouling populations. For example, Weiss (1948), in a fouling survey in Biscayne Bay, Florida, observed that lighter fouling prevailed at the southern part of the bay, which was in relatively free communication with the open sea, than in the somewhat isolated northern part, where the water was polluted, contained much suspended detritus and was moved by strong tidal currents. A second factor likely to contribute to a high fouling intensity in the port is the proximity of extensive adult populations of fouling species on wharf piles, moored craft, tenders, and berthed vessels. Not only may these populations be a source of larvae for new attachments, but, as indicated by Knight-Jones and Crisp (1953) in consideration of barnacle fouling, their presence may influence larval behaviour prior to settlement in such a way as to induce exceptionally heavy fouling of surfaces in the immediate vicinity. Finally, as is common in the partially enclosed coastal waters of harbours and bays, the waters of Auckland Harbour are heavily charged with silt and other suspended detritus which may have had various effects on the settlement and growth of fouling organisms. Skerman (1956) found that much material of this nature rapidly became incorporated in primary films developed on submerged glass slides, particularly when these were exposed in regions sheltered from the main tidal flow, and that these granular films appeared to promote barnacle settlement on these surfaces. A development of similar silt-laden films on test panels at Kauri Point may have contributed to the particularly heavy initial settlement of barnacles observed at this sheltered site, but, as suggested previously, continued deposition of this material may have been a factor eventually militating against the survival of these pioneer populations.

Comparison between the fouling occurring at the ports of Auckland and Lyttelton (Skerman, 1958b) shows that a number of the prominent species appear in both regions—viz., *Navicula grevillei, Bugula flabellata, Hydroides norvegica, Elminius modestus, Corella eumyota, Asterocarpa cerea, Diplosoma macdonaldi,* and *Botryllus schlosseri.* With the exceptions of *Corella and Asterocarpa,* however, all of these are recognized as fouling species in many other regions of the world. Recent studies in Australian ports (Allen and Wood, 1950; Wood and

Allen, 1958) are also indicative of resemblances in fouling between Sydney and Auckland. To these ports, *Bugula neritina and B. flabellata, Hydroides norvegica, Balanus amphitrite* var. *cirratus* and *B. trigonis, Styela plicata* and *Botryllus schlosseri* are common, and it is probable that close similarities in terms of sea temperature, pollution, and topography in these ports may contribute to some correspondence in ecological conditions under which fouling develops.

Allen (1953), who regarded the ubiquitous occurrence of many fouling organisms as being due largely to their translocation on ships, adduced considerable evidence in favour of his suggestion that shipping movements played an important part in the introduction of certain fouling species to Australian waters from where they were previously unknown. The regular traffic of commercial shipping between Sydney and Auckland may, in the light of Allen's propositions, be responsible not only for existing similarities in certain components of fouling at the two ports, but also for the future introduction of new species from one to the other. In this latter respect, of particular economic importance is the polyzoan, *Watersipora cucullata* (Busk), a prominent ship-fouling species in all but the southern Australian waters and which is reputed to have a high tolerance to copper (Wood and Allen, 1958). There is, at present, no evidence of this form having yet become established within the Port of Auckland.

Acknowledgements

References

Alllen, F. E., 1953: Distribution of Marine Invertebrates by Ships. *Aust. J. Mar. Freshw. Res. 4 (2)*: 307–16.

Allen, F. E.; Wood, E. J. F., 1950: Investigations on Underwater Fouling: 2— The Biology of Fouling in Australia: The Results of a Year's Research. *Ibid., 1 (1)*: 92–105.

Barnes, H., 1948: Studies on Anti-fouling Compositions: Part 4—The Relationship between Leaching Rate, Copper Loss, and Anti-fouling Performance, Under Raft and Service Conditions. *J. Iron St. Inst.* June 1948: 175–185.

Brewin, Beryl I., 1948: Ascidians of the Hauraki Gulf: Part 1. *Trans. roy. Soc. N.Z. 77 (1)*: 115–38.

Cole, H. A.; Knight-Jones, E. W., 1949: The Setting Behaviour of Larvae of the European Flat Oyster, *Ostrea edulis* L., and its Influence on Methods of Cultivation and Spat Collection. *Fish. Invest. Lond.,* Ser. 2, *17 (3)*.

Dellow, Vivienne, 1955: Marine Algal Ecology of the Hauraki Gulf, New Zealand. *Trans. roy. Soc. N.Z. 83 (1)*: 1–91.

Department of Scientific and Industrial Research: "Deterioration of Timber, Metal, and Concrete Structures Exposed to the Action of Sea Water." Reports of the Committee of the Institution of Civil Engineers, 1920–51. H.M.S.O., London.

Hendey, N. Ingram, 1951: Littoral Diatoms of Chichester Harbour, with Special Reference to Fouling. *J. R. micr. Soc. 71*: 1–86.

Hounsell, W. K., 1935: Hydrographic Observations in Auckland Harbour. *Trans. roy. Soc. N.Z. 64 (3)*: 257–71.

Knight-Jones, E. W., 1948: *Elminius modestus*: Another Imported Pest of East Coast Oyster Beds. *Nature, Lond. 161*: 201.

Knight-Jones, E. W.; Stevenson, J. P., 1950: Gregariousness During Settlement in the Barnacle *Elminius modestus* Darwin. *J. Mar. biol. Ass. U.K.* **29**: 281–97.

Knight-Jones, E. W.; Crisp, D. J., 1953: Gregariousness in Barnacles in Relation to the Fouling of Ships and to Anti-fouling Research. *Nature, Lond. 171*: 1109–10.

Korringa, P., 1940: Experiments and Observations on Swarming, Pelagic Life, and Setting in the European Flat Oyster, *Ostrea edulis* L. *Arch. neerl. Zool. 5*: 1–249.

————, 1952: Recent Advances in Oyster Biology. *Quart. Rev. Biol. 27 (3)*: 266–308; *(4)*: 339–65.

Lynch, W. F., 1958: Factors Influencing Metamorphosis of Larvae of Some of the Sessile Organisms. *15th Internat. Congr. Zool., Sect. 3,* Paper 9, 3 pp. (Abstra.)

MacGinitie, G. E.,; MacGinitie, N., 1949: "Natural History of Marine Animals." McGraw-Hill, N.Y. 473 pp.

Miller, M. A.; Rapean, J. C. Whedon, W. F., 1948: The Role of Slime Film in the Attachment of Fouling Organisms. *Biol. Bull. Woods Hole, 94*: 143–7.

Oliver, W. R. B., 1923: Marine Littoral Plant and Animal Communities in New Zealand. *Trans. N.Z. Inst. 54*: 496–545.

Paul, M. D., 1942: Studies on the Growth and Breeding of Certain Sedentary Organisms in the Madras Harbour. *Proc. Indian Acad. Sci., 15*ʙ *(1)*: 1–42.

Powell, A. W. B., 1937: Animal Communities of the Sea-bottom in Auckland and Manukau Harbours. *Trans. roy. Soc. N.Z. 66 (4)*: 354–401.

Prytherch, H. F., 1934: The Role of Copper in the Setting Metamorphosis and Distribution of the American Oyster, *Ostrea virginica. Ecol. Monogr. 4*: 49–107.

PYEFINCH, K. A.; DOWNING, F. S., 1949: Notes on the General Biology of *Tubularia larynx* Ellis and Solander. *J. Mar. biol. Ass. U.K. 28* : 21–43.

RALPH, PATRICIA M., 1953: A Guide to the Athecate Hydroids and Medusae of New Zealand. *Tuatara 5 (2)* : 59–75.

RALPH, PATRICIA M.; HURLEY, D. E., 1952: The Settling and Growth of Wharf-pile Fauna in Port Nicholson, Wellington, New Zealand. *Vict. Univ. N.Z. Zool. Publ. 19*.

RILEY, G. A., 1937–38: The Significance of the Mississippi River Drainage for Biological Conditions in the Northern Gulf of Mexico. *J. Mar. Res. 1 (1)* : 60–73.

SKERMAN, T. M., 1956: The Nature and Development of Primary Films on Surfaces Submerged in the Sea. *N.Z. J. Sci. Tec. 38 B* : 44–57.

————, 1958a: Seasonal Variations in Sea-water Surface Temperatures within New Zealand Harbours. *N.Z. J. Geol. Geophys. 1 (1)* : 197–218.

————, 1958b: Marine Fouling at the Port of Lyttelton. *N.Z. J. Sci. 1 (2)* : 224–57.

WALLACE, G. M.; NEWMAN, LORRAINE E., 1953a: Bacteriological Survey of Auckland Harbours: 1—Extent of Sewage Fields in Waitemata Harbour. *N.Z. J. Sci. Tech. 34 B (6)* : 515–22.

————, 1953b: Bacteriological Survey of Auckland Harbours: 2—Condition of Beaches to the East of Orakei Sewer Outfall, Waitemata Harbour. *Ibid., 35 B (3)* : 225–38.

WALLACE, G. M.; NEWMAN, LORRAINE E.; JERROME JACQUELINE L., 1958: Bacteriological Survey of Auckland Harbours: 5—Vertical Distribution of Sewage in Waitemata Harbour. *N.Z. J. Sci. 1 (1)* : 23–34.

WEISS, C. M., 1948: The Seasonal Occurrence of Sedentary Marine Organisms in Biscayne Bay, Florida. *Ecology 29 (2)* : 153–72.

WOOD, E. J. F.; ALLEN, F. E., 1958: "Common Marine Fouling Organisms of Australian Waters." Department of the Navy, Melbourne, 23 pp. and illus.

WOODS HOLE OCEANOGRAPHIC INSTITUTION (COMP.), 1952: "Marine Fouling and its Prevention." Prepared for Bureau of Ships, Navy Department, United States Naval Institute, Annapolis, Maryland. 388 pp.

ACETATES OF DIHYDROQUERCETIN (TAXIFOLIN)

By H. V. Brewerton, Dominion Laboratory, Department of Scientific and Industrial Research, Wellington and R. C. Cambie, Department of Chemistry, University of Auckland

Summary

The penta- and tetra-acetates of racemic and optically active dihydroquercetin have been prepared and their properties compared.

Introduction

When investigating the extractives of *Quintinnia serrata,* one of the authors (R.C.C., unpublished work) isolated (±)-dihydroquercetin as the hydrolysis product of the 3-rhamnoside, astilbin. The aglycone formed a penta-acetate, the melting point of which (152° to 153° C) agreed with that reported by other workers (Kondo, 1951; Nishida *et al.,* 1952; Kurth *et al.,* 1955) for the acetyl derivative of racemic dihydroquercetin but differed markedly from that of the optically active penta-acetate (82° to 84° C) reported previously (Brewerton, 1957). As the melting point of the racemic acetate was very similar to that recorded for the (+)-tetra-acetate (152° C) by Brewerton, in seemed desirable to show conclusively that the former was in fact fully acetylated and to confirm the nature of the latter by preparing a tetra-acetate of (±)-dihydroquercetin. Furthermore, if it were shown that there are appreciable differences between the melting points of corresponding derivatives of racemic and optically active dihydroquercetin, this might partly explain the variety of melting points attributed to the penta-acetate of taxifolin in the literature.

Accordingly, a series of acetylations of (±)-dihydroquercetin, m.p. 239° to 240° C, $[a]_D^{25}$ 0° (c, 1·34 in 50% Me_2CO) and (+)-dihydro-quercetin, m.p. 235° to 237° C, $[a]_D^{20}$ + 45° (c, 1·0 in 50% Me_2CO) were carried out and the results are now reported.

Dihydroquercetin Penta-Acetates

The racemic and optically active penta-acetates were consistently prepared by treating the parent flavanones (0·0003 to 0·0005 mol.) in acetic anhydride (0·01 to 0·03 mol.) with heating (100° C to reflux

temperature) for periods up to 5 hours using as catalyst (a) fused sodium acetate, or 1 drop of (b) pyridine, (c) concentrated sulphuric acid, (d) 60% perchloric acid. They were also prepared using acetic anhydride/1 drop pyridine at 35° C for 24 hours.

(±)-dihydroquercetin penta-acetate crystallized from methanol as colourless needles, m.p. 152° to 153° C.

Analysis—Found: C, 58·7; H, 4·3; CH_3CO, 40·9.

$C_{23}H_{22}O_{12}$ requires: C, 58·4; H, 4·3; $5CH_3CO$, 41·8%.

(+)-dihydroquercetin penta-acetate crystallized from ethanol as colourless needles, m.p. 118° to 119° C.

Analysis—Found: C, 58·5; H, 4·2; CH_3CO, 40·8%.

Neither derivative gave coloration with alcoholic ferric chloride nor dissolved immediately in cold aqueous sodium hydroxide (10%).

Dihydroquercetin Tetra-Acetates

The racemic and optically active tetra-acetates were prepared by the method of Simokoriyama (1941) by treating the parent flavanones (0·0005 mol.) with acetic anhydride (0·005 mol.) and 2 to 3 drops of pyridine with stirring at room temperature for 3 minutes. Treatment with acetic anhydride/1 drop pyridine at 0° to 10° C for 16 hours gave low yields of the tetra-acetates.

The racemic tetra-acetate was also prepared by partial de-acetylation of (±)-dihydroquercetin penta-acetate with 2N sulphuric acid for 2 hours at room temperature (Mahesh et al., 1956).

(±)-dihydroquercetin tetra-acetate crystallized from ethanol as colourless needles, m.p. 159° to 161° C.

Analysis—Found: C, 58·5; H, 4·1; CH_3CO, 34·4.

$C_{23}H_{20}O_{11}$ requires: C, 58·5; H, 4·2; $4CH_3CO$, 36·4%.

(+)-dihydroquercetin tetra-acetate crystallized from methanol as colourless needles, m.p. 151° to 152° C. The melting point was undepressed on admixture with the tetra-acetate previously prepared (Brewerton, 1957).

Analysis—Found: C, 58·4; H, 4·3; CH_3CO, 36·1%.

Both derivatives gave red coloration with alcoholic ferric chloride and were immediately soluble in cold aqueous sodium hydroxide (10%).

ABSORPTION SPECTRAL DATA

Dihydroquercetin derivative	M.p.	Infra-red bands cm⁻¹ (Nujol)	Ultra-violet bands mμ	log ε
(±)-penta-acetate	152° to 153° C	1770 (acetate) 1740 (acetate) 1705 (conjugated CO)	264 313	4·12 3·61
(+)-penta-acetate	118° to 119° C	1770 (acetate) 1742 (acetate) 1705 (conjugated CO)	261 314	4·10 3·58
(±)-tetra-acetate	159° to 161° C	3320 (weak, OH) 1760 (broad, acetate) 1680 (conjugated CO)	274 335	4·20 3·60
(+)-tetra-acetate	151° to 152° C	3320 (weak, OH) 1770 (acetate) 1745 (acetate) 1680 (conjugated CO)	277 340	4·15 3·60

When working with either the penta- or tetra-acetates of dihydro-quercetin, it was found that if the compounds were precipitated from ethanolic solution the melting point of each compound was lowered to 80° C or less and could not be raised above 82° to 84° C by re-precipitation. This gives an explanation for the low melting point of the (+)-penta-acetate previously reported (Graham and Kurth, 1949; Brewerton, 1957). This derivative was obtained crystalline during the present work and the melting point was raised to 118° to 119° C. The difference in melting points between the racemic and optically active penta-acetates of dihydroquercetin is therefore 34° C.

In elementary analyses of the penta- and tetra-acetates of dihydro-quercetin the carbon and hydrogen values are ambiguous.

Calculated for penta-acetate: C, 58·37; H, 4·31.

Calculated for tetra-acetate: C, 58·47; H, 4·27%.

Differentiation between a penta- and a tetra-acetate by analysis therefore depended on acetyl values and these were significant. The parent compound, dihydroquercetin, gave a blank acetyl value of 3·29% and a proportionate correction has been applied to the acetyl values obtained for the derivatives.

As expected, the ultra-violet absorption spectra of both the racemic and optically active penta-acetates were similar to that of flavanone (λ max. 250 mμ and 320 mμ). Those of both the tetra-acetates showed bathochromic shifts attributable to the presence of the auxocrhomic 5-hydroxyl group.

The infra-red spectra of corresponding derivatives of racemic and optically active dihydroquercetin were virtually identical. The carbonyl bands of the penta- and tetra-acetates, relative to those of flavanone (1680 cm^{-1}) and 5-hydroxyflavanones (1640 cm^{-1}) (Hergert and Kurth, 1953), show frequency increases of 25 and 40 wavenumbers respectively. In each case this is attributed to interaction between the carbonyl and vicinal acetyl groups as in steroidal α-keto-acetates (Bellamy and Williams, 1957; Jones and Roberts, 1957).

ACKNOWLEDGEMENTS

REFERENCES

BELLAMY, L. J.; WILLIAMS, R. L., 1957: *J. chem. Soc.*, 861.

BREWERTON, H. V., 1957: *N.Z. J. Sci. Tech., B38* : 697.

GRAHAM, H. M.; KURTH, E. F., 1949: *Industr. enyng. Chem. (Industr.), 41* : 409.

HERGERT, H. L.; KURTH, E. F., 1953: *J. Amer. chem. Soc., 75* : 1622.

JONES, R. N.; ROBERTS, G., 1957: *Chem. & Ind.*, 1269.

KONDO, T., 1951: *J. Fac. Agr. Kyushu Univ. 10* : 79; read only in *Chem. Abstr. 47* : 4602.

KURTH, E. F.; HERGERT, H. L.; ROSS, J. D., 1955: *J. Amer. chem. Soc., 77* : 1621.

MAHESH, V. B.; NEELAKANTAN, S.; SESHADRI, T. R., 1956: *J. sci. industr. Res. India, B15* : 287.

NISHIDA, K.; ITO, H.; KONDO, T., 1952: *J. Japan tech. Assoc. Pulp Paper Ind., 6* : 261, 322; read only in *Chem. Abstr. 46* : 11343.

SIMOKORIYAMA, M., 1941: *Bull. chem. Soc. Japan, 16* : 284; read only in *Chem. Abstr. 36* : 2864.

A PROPOSED METHOD OF SURVEYING THE WAVE STATE OF THE OPEN OCEAN

By N. F. BARBER, Dominion Physical Laboratory, Department of Scientific and Industrial Research

Summary

The directional spectrum of waves and swell in the open sea might be estimated quickly by an aircraft carrying a swept-frequency radar working at frequencies between $\frac{1}{2}$ Mc/s and 10 Mc/s and using a long trailing aerial to get directivity. A system of floating buoys is also described, which may serve to measure the directional spectrum when the radio aircraft is to be calibrated experimentally against known sea-states.

INTRODUCTION

Observations of the state of the sea in the North Atlantic are currently being made among their other duties, by Weather Ships that assist the Meteorological Services and guard the safety of transatlantic air routes. The wave measuring device is one devised by Tucker (1956). On other oceans this service is not available, but for scientific or commercial purposes a survey of the wave state in open water may be desired. The following is a proposal for a radio method of survey. Some apology is perhaps needed for setting out a proposal before the ideas have been tested experimentally, but such experiments must necessarily be very costly.

A RADIO SURVEY METHOD

Crombie (1955) has shown that vertically polarized radio waves striking the sea at grazing incidence are reflected from the sea as from a complicated diffraction grating. The back-scattered signals come from water waves whose wavelength is half that of the radio waves and which are oriented with their wave crests at right-angles to the direction of transmission. The back-scattered signals show a Doppler shift in frequency, proportional to the velocity of the water waves. This work was done with a radar of $13 \cdot 56$ Mc/s selecting sea waves of length 37 ft. Ingalls and Stone (1957) report similar experiments made at 18 and 24 Mc/s which support the interpretations made by Crombie. They estimate that the sea acts as a target whose cross-section for reflection is about 10^{-4} sq.m. for every square metre of sea surface. The frequencies they use are reflected from short water-waves (length 21 ft or 28 ft) whose height may be perhaps $\frac{1}{10}$ of their length. It may rea-

sonably be assumed that the reflecting power of waves is proportional to the ratio of wave height to wavelength. Table 1 lists the radio frequency that would be needed to examine sea waves of various periods, and gives an estimate of the effective reflecting target (as a fraction of the area of sea surface selected by the gates of the radar) for some wave heights which might be encountered in practice.

TABLE 1.—Estimated Target Areas in sq.m. per sq.m. of Sea Surface for Typical Sea Waves.

Wave period (sec.)	Sea wavelength (ft)	Radio frequency (Mc/s)	Assumed wave height (ft)	Target area
3	45	10·5	3	$0·6 \times 10^{-4}$
5	125	4	6	$0·5 \times 10^{-4}$
7	250	2	15	$0·6 \times 10^{-4}$
10	500	1	8	$0·16 \times 10^{-4}$
14	1000	0·5	5	$0·05 \times 10^{-4}$

Similar experiments, but at a radio frequency of only 1·85 Mc/s, are reported by Anderson (1956) who has made an extensive study of the sea clutter observed from Loran pulse transmissions. The echoes showed a Doppler shift, producing beats of the period of the selected water waves, in this case a little over 7 sec. The echoes tended to be polarized with the electric vector vertical. The equivalent target area at a range of 100 km was estimated as 7×10^5 sq.m. This is about 10 times larger than would be inferred from Table 1. The echoes are therefore quite strong.

Wave Survey From an Aircraft

It is clear that the reflection of radio waves might be used to discover the direction and height of sea waves. For open-sea surveys it would be desirable to operate the radio transmitter from an aircraft. Gassmann (1957) is reported as having fitted an airplane with a standard sweep-frequency ionosphere recorder for the purpose of measuring ionospheric movements, and a similar system should serve for wave study if the transmission were horizontally directive.

A long trailing steel wire aerial seems suitable, about 2 mm in diameter and 4,000 ft long. Schelkunoff and Friis (1952, figs 13, 15) quote the impedance of a long wire of this diameter as between 11,000 and 13,000 ohm for frequencies between 10 Mc/s and $\frac{1}{2}$ Mc/s. At 1 Mc/s the effective resistance of the wire (specific resistance 40 ohm cm and permeability 100) is 670 ohm per wavelength (1000 ft) so about half the power is absorbed, per wavelength, in resistive losses. The long aerial would therefore not be resonant.

The polar diagram of the aerial depends on the current attenuation per wavelength. For the various frequencies considered, this attenuation is listed in Table 2, assuming it to be due entirely to resistive losses. Terman (1937, sec. 131, foonote) gives a formula for the polar diagram and this is sketched in Fig. 1 for frequencies of $\frac{1}{2}$, 2, and $10\frac{1}{2}$ Mc/s.

TABLE 2.—Current Attenuation per Wavelength of Steel Wire 2 mm Diameter Assuming spec. res. 4×10^{-5} ohm cm, permeability 100.

Radio freq. (Mc/s)	Radio wavelength (ft)	Current attenuation per wavelength
10·5	90	·92
4	240	·81
2	500	·68
1	1000	·50
0·5	2000	·33

It appears that to give transmission in the useful direction, about 5° below the horizontal, the wire should trail at about 30° to the horizontal as illustrated in Fig. 1. The airspeed necessary to make the wire trail at this angle is a matter for trial but about 100 f.p.s. seems probable. The tension in the wire at its point of attachment will be about twice its weight, about 120 lb. This is rather less than half its breaking load.
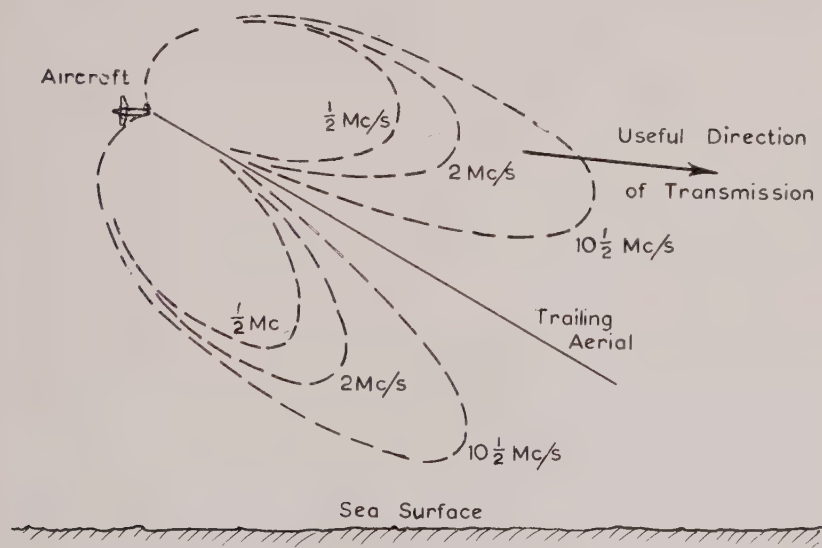
FIG. 1.—A radio system for surveying wave conditions in open water.

Because the polar diagram is conical about the direction of the aerial a wide angle of sea is irradiated but the radiation on the flanks is less effective in producing reflections because its electric vector is nearly horizontal.

To survey an area of sea the aircraft would fly on a fixed course and a record would be made of the smoothed echo power as the frequency was swept through the range $\frac{1}{2}$ to $10\frac{1}{2}$ Mc/s. A calibration would then relate the power at the various frequencies to the wave height of the corresponding sea waves. This would be repeated on various directions of flight say six directions at intervals of 30°.

Records made in this way do not distinguish between waves travelling in opposite senses. If the sense of travel cannot be inferred from the direction of the wind it may be deduced from the frequency of beats between the echo and a signal from the transmitter oscillator, the frequency being kept constant for this purpose. The beat frequency will depend on the true ground speed. Table 3 lists the beat frequencies for waves meeting and waves following the aircraft if its ground speed is 100 f.p.s.

TABLE 3.—Beat Frequencies of Echo and Transmission for a Ground Speed of 100 f.p.s. in the Line of Transmission.

Sea waves			Beat frequency	
Period (sec.)	Wavelength (ft)	Velocity (f.p.s.)	Following (c/s)	Meeting (c/s)
3	45	15	1·9	2·5
5	125	25	0·6	1·0
7	250	35	0·26	0·54
10	500	50	0·10	0·30
14	1000	70	0·03	0·17

The beat frequencies for following waves and for meeting waves are very different and a record covering a few cycles (a minute or less) would be sufficient to establish the sense of travel.

ABSOLUTE CALIBRATION

The radio-aircraft system needs to be calibrated by using it first to observe seas whose wave state has been measured in some more direct way. This might be done in conjunnction with Weather Ships in the North Atlantic but the analysis of the sea state which they provide is not complete. The following system of floating buoys aims to give a complete analysis. It is too cumbersome for routine use but it may provide the absolute measure against which the radio-aircraft could be calibrated.

The vertical displacements of a floating buoy may be detected by its displacement relative to that of a horizontal flat plate suspended at some distance below it on an extensible cord. The varying tension of the cord is proportional to the displacement of the buoy. A line array of such buoys could be made into a direction-sensitive system. The disadvantage

of a line array is that it does not usually distinguish between waves that approach the line at equal angles of incidence from opposite sides. This limitation is overcome if records are also made of the tilts of the water surface in the direction at right-angles to the line array. In practice records could be made of the angles of tilt of flat raft-like buoys relative to the directions of pull of the cord suspending the flat plate below each of them. The proposed arrangement is illustrated in Fig. 2. The buoys are nominally stationed at intervals of 15 30 60 120 240, and 480 ft. On the average they should occupy these stations but the connections must allow the buoys to move horizontally with the waves as well as vertically.
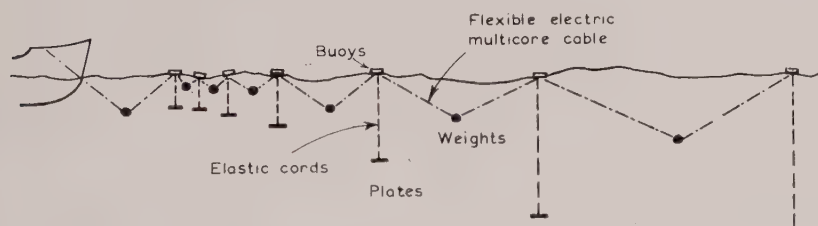
FIG. 2.—A system of floating buoys for measuring the wave conditions in open water.

The line of buoys must extend in a direction that remains fixed during the time which the records are taken. This time may be an hour. Only one direction appears practicable, that of the wind. One end of the line may be attached to a sea anchor and the other end pulled slowly by the recording ship. It would be desirable to record all fourteen signals, that is, the elevations and tilts of seven buoys, on multi-channel magnetic tape and to analyse these records at leisure.

ANALYSIS

The full directional spectrum of sea waves shows the distribution of wave power on a polar plot whose co-ordinates are the direction of wave travel and the wave number (or the wavelength or the wave frequency). However, the analysis will deal separately with separate narrow ranges of wave frequency, so that at any stage the aim is to discover the distribution of wave power, around some narrow annular zone of the directional spectrum. This distribution may be expressed as a coefficient of power density $E(\theta)$, or power per unit angle of waves travelling in the direction θ. This function can be expanded as a Fourier series

$$E(\theta) = A_0 + A_1 \cos \theta + A_2 \cos 2\theta + \ldots \\ B_1 \sin \theta + B_2 \sin 2\theta + \ldots \qquad \ldots \ldots (1)$$

The present array of buoys, like every other direction-finding system acts through its observation of the space correlogram of the waves. If two buoys are separated by a space interval whose length and direction are denoted in polar co-ordinates as (r, a), and if these buoys detect fluctuating elevations of the water surface, say h_1 and h_2, the "correlation" between the two signals is defined here as $\rho(r, a)$ where

$$\rho(r, a) = \overline{h_1 h_2^*}$$

The asterisk denotes the complex conjugate and the bar denotes the time average of the product. The complex notation is adopted in order to distinguish between waves travelling in opposite directions. The actual signals from the buoys are of course real, but the frequency filters can be designed so as to transmit complex signals near to a frequency $+ f_0$ and to reject their counterparts having frequencies near to $- f_0$. Methods of designing such filters and of getting the complex correlation have been described elsewhere (Barber, 1954, 1957; Barber and Doyle, 1956).

By a well known theorem the space correlogram of the waves, that is the plot of correlations for all possible space intervals, is the Fourier transform of the power spectrum. In polar co-ordinates where (r, a) are the co-ordinates in the correlogram and (k, θ) are the co-ordinates in the power spectrum, k being reciprocal wavelength, the general relation would be written

$$\rho(r, a) = \int_0^\infty dk \int_0^{2\pi} d\theta\ E(k, \theta)\ \exp i\ [2\pi k r \cos (\theta - a)]$$

$$\text{............ (2)}$$

In the present problem where filters restrict attention to waves whose k values lie in a narrow range about some selected value k_0 it is sufficient to consider only the power per unit angle, $E(\theta)$

$$E(\theta) = \int_0^\infty E(k, \theta) dk \qquad \text{............ (3)}$$

and the general relation reduces to

$$\rho(r, a) = \int_0^{2\pi} d\theta\ E(\theta)\ \exp i\ [2\pi k_0 r \cos (\theta - a)]$$

$$\text{............ (4)}$$

If $E(\theta)$ is expressed as the harmonic series in eq. (1), the integral can be evaluated using Hansen's representation of the first kind of Bessel function, namely

$$J_n(z) = \frac{i^{-n}}{2\pi} \int_0^{2\pi} e^{iz \cos \phi} \cos n\phi \, d\phi \qquad \text{.........} \quad (5)$$

and the correlogram becomes

$$\rho(r, a) = 2\pi \sum_0^{s = \infty} i^s \left[A_s \cos sa + B_s \sin sa \right] J_s \left(2\pi k_0 r \right)$$

$$\text{..........} \quad (6)$$

It is therefore the sum of a number of patterns, one corresponding to each of the terms in the harmonic expansion of $E(\theta)$. Each pattern shows a sinusoidal variation with the direction θ and is distributed radially according to the appropriate Bessel function. It may be remarked that this separation into harmonics is merely formal, because all terms in eq. (1) except the first propose negative energies at some directions of travel and cannot individually correspond to any actual system of waves. However, the harmonic treatment is a useful method of analysis and in any actual problem the total power density $E(\theta)$ will be essentially positive.

Having measured experimentally certain values of the correlogram the problem of analysis is to deduce the amplitudes of the component patterns, that is the coefficients A_0 A_1 B_1 A_2 B_2, etc. These may then be used to synthesize the spectrum $E(\theta)$ from eq. 1.

The system of buoys suggested in Fig. 2 may be assumed to lie along the direction of a zero. Correlations may be evaluated between the elevations signalled from pairs of buoys at many different separations (integral multiples of 15 ft) but a is zero for all these intervals. From equation (6) the formula for the correlation at a zero is

$$\rho(r, 0) = 2\pi \sum_0^{s = \infty} i^s A_s J_s \left(2\pi k_0 r \right) \qquad \text{..........} \quad (7)$$

The problem is therefore to choose values of the coefficients A so that the curve of eq. (7) fits the complex values of correlation measured at the various space intervals r. The wavelength of the sea waves, $1/k_0$ is known by the selected frequency. The values of the quantities $J_s(2\pi k_0 r)$ for the different space intervals can be read from the British Association Mathematical Tables, Vol. VI and XI (C.U.P. 1950 and 1952).

There appears to be no exact method for finding the values of the coefficients A, but the work is simplified if correlations are measured at distances near to multiples of a quarter of the sea wavelength. The argument $2\pi k_0 r$ is then near to 0, $\pi/2$, π, . . etc. Considering, for instance, the real parts of the correlations, these depend on the J functions of even order which are sketched in Fig. 3. It will be seen that the correlation at zero interval depends only on J_0, that at one-quarter wavelength interval depends mainly on J_0 and J_2, J_4 being small, the correlation at a half wavelength interval depends primarily on J_0, J_2, and J_4, and so on. The curves of the odd order Bessel functions show a similar tendency. Eq. (7) therefore leads to two sets of simultaneous equations involving the A coefficients of odd and even order. Approximate values of the coefficients are got quite readily and can be improved by iteration.
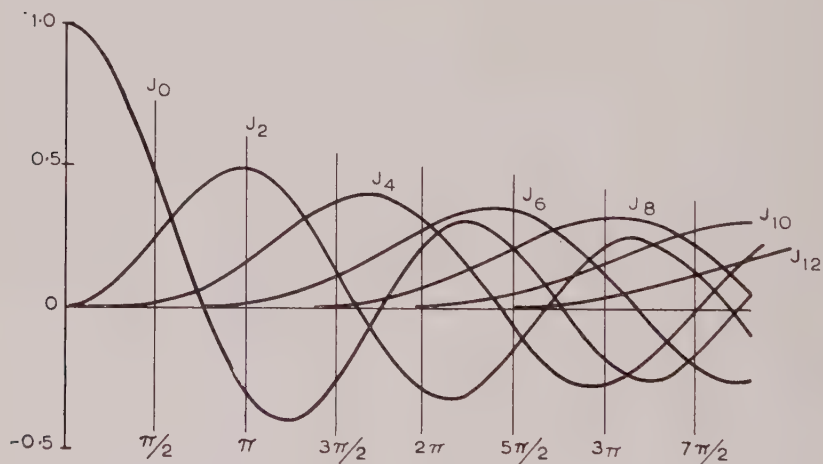
Fig. 3.—Bessel functions $J_s (2\pi kr)$ of even order.

The variety of intervals presented by the arrangement proposed in Fig. 2 allows study of a range of wavelengths. Thus, intervals equal to 15, 30, 45, 60, and 90 ft (multiples of 15 ft) are suited for waves of length near to 60 ft (period $3\frac{1}{2}$ sec.) while intervals of 240, 480, 702, and 935 ft are suitable for wavelengths near to 1000 ft (period 14 sec.).

The B coefficients in eq. (1) cannot be found from correlations between the elevations of the buoys. These coefficients concern the part of the power spectrum which is antisymmetrical about the line of buoys. However, the tilt of a buoy is the gradient of elevation, and the correlation between the elevation of one buoy and the tilt of another is a measure of the gradient on the correlogram. The gradient across the a axis is due entirely to the B coefficients. Using for the moment rectangular x y axes with the x axis along the line of buoys,

$$\overline{\frac{\partial h_1}{\partial y} . h_2^*} = \frac{\partial \rho}{\partial y} (x, y) \Bigg|_{\substack{x = r \\ y = 0}} = \frac{1}{r} \frac{\partial \rho}{\partial a} (r, a) \Bigg|_{a = 0}$$

.... (8)

By differentiation of eq. (6), setting a as zero

$$\overline{\frac{\partial h_1}{\partial y} . h_2^*} = 2\pi \sum_{1}^{s = \infty} \frac{s}{r} i^s B_s J_s (2\pi k_0 r)$$

.... (9)

Measurements of the correlation between tilt and elevation at suitable intervals enables the coefficients B to be found in a manner similar to that used for the A coefficients.

When all the coefficients are known the distribution $E(\theta)$ is calculated from eq. (1).

It seems likely that coefficients could be found up to the 8th order. If higher coefficients are ignored this leads to some lack of resolution in direction. For instance, a single long-crested train of swell appears as a delta function in the power spectrum, but the sum of harmonics up to the 8th order gives merely the continuous curve shown in Fig. 4. The central peak has an angular width of 42° between zeros. More complicated spectra are blurred in a similar way. It may be remarked, however, that when impossible negative values of power density appear, as they do in this instance, Longuet-Higgins (1955) has shown how they can be made to give further information about the power distribution.
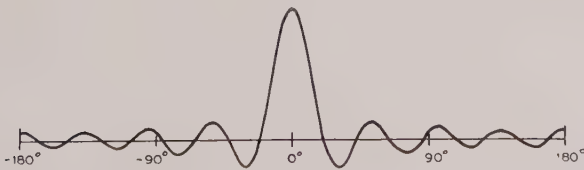

FIG. 4.—The spectrum of swell from a single direction, reconstructed by using coefficients up to order 8. The angular width of the central peak between zeros is 42°.

REFERENCES

ANDERSON, E. P. in press: Characteristics of Sea Reflections at 1·85 Mc. Stanford University report on Low Frequency Propagation Studies, Part II. June 1953 to September 1956.

BARBER, N. F., 1954: Finding the Direction of Sea Waves. *Nature, 174* : 1048.

————, 1957: A Scatter Diagram which gives the Complex Correlation Coefficient for Normal Variables. *N.Z. J. Sci. Tech. B38* : 366.

————; DOYLE, D., 1956: A Method of Recording the Direction of Travel of Ocean Swell. *Deep Sea Res. 3* : 206.

CROMBIE, D. D., 1955: Doppler Spectrum of Sea Echo at 13·56 Mc/s. *Nature 175* : 681.

GASSMAN, G. F., 1957: "The U.S. I.G.Y. Program in Ionospheric Physics". Report by M. G. Morgan, Dartmouth College, Hanover, New Hampshire.

INGALLS, R. P.; STONE, M. L., 1957: "Characteristics of Sea Clutter at H.F." Abstract in Trans. I.R.E. Vol. AP-5 Jan. 1957 : 164.

LONGUET-HIGGINS, M. S., 1955: Bounds for the Integral of a Non-negative Function in Terms of its Fourier Coefficients. *Proc. Camb. phil. Soc., 51* : 590-603.

SCHELKUNOFF, S. A.; FRIIS, H. T., 1952: "Antennas; Theory and practice". John Wiley, New York, Chapman & Hall, London.

TERMAN, F. E., 1937: "Radio Engineering", McGraw Hill.

TUCKER, M. J., 1956: A Ship-borne Wave Recorder. *Trans. Instn. nav. Archit. Lond. 98* : 236.

THE SOLUBILIZATION OF "INSOLUBLE" PHOSPHATE

4—THE REACTION BETWEEN ORGANIC ACIDS AND TRICALCIUM PHOSPHATE

By H. W. Johnston, Imperial Chemical Industries (N.Z.) Ltd., Wellington, and R. B. Miller, Soil Bureau, Department of Scientific and Industrial Research, Wellington

Summary

When organic acids act on tricalcium phosphate under acid conditions, the extent of the reaction is determined by the strength of the acid as indicated by its dissociation constant and by the ability of the acid anion to form unionized or precipitated compounds with calcium. As the structure of the acid affects both the acid strength and the ability of the anion to form association compounds the extent of the reaction may be related to the structure of the acid.

Introduction

In earlier papers in this series (Johnston, 1952, 1954a, 1954b) the dissolving effect of a number of organic acids on tricalcium phosphate was described. It appeared from this work that α–hydroxy acids were generally more effective in bringing phosphate into solution than other acids used. Because these acids are important in soil and fertilizer chemistry as well as in other fields such as medicine and dentistry, it was decided to make further investigations into the nature of these reactions.

Literature

Greenwald (1938) investigated the ability of calcium to form complexes with organic anions and the effect of the formation of these complexes on the solubility of tricalcium phosphate in organic acids. Johnston (1956) has recently reviewed work on association between calcium and organic anions and shown that such association frequently occurs.*

---

*To describe this type of unionized association Johnston used the term "chelation" in its broad sense. In this paper, to avoid possible ambiguity, "association" will be used.

In a comprehensive study of the solubility relationships of a tertiary calcium phosphate, Mattson, Andersson, Miller, and Vahtras (1951) used β–humus which contains organic acids and showed that it greatly increases the phosphate solubility. The increase was ascribed to the surface displacement of phosphate by humate ions.

Preliminary Discussion

In the experiments reported previously in this series (Johnston, 1954a), 1 gram of tricalcium phosphate was shaken for 48 hours with 30 ml of N/10 acid. The suspension was then filtered and phosphate determined in the filtrate. In water 26 mg P_2O_5/100 ml came into solution, and in the acids much more.

The reactions involved in bringing phosphate into solution may, as shown by Mattson *et al.* (1951), be complex; but under the acid conditions used here direct acid dissolution must be the primary one. The extent of the dissolution will be increased by any reactions that tend to remove the dissolution products from solution.

The precipitation of an insoluble calcium salt would do this. Oxalic acid was included in the original series because calcium oxalate is very insoluble, and the reaction with calcium phosphate would therefore be expected to go to completion. Some of the other acids, such as tartaric, also have calcium salts of low solubility, and they too brought large amounts of phosphate into solution. The solubilities of some calcium salts in g/100 ml water (20° C) are as follows (Seidell, 1940):

oxalate	0·006	succinate	1·3
tartrate	0·04	salicylate	2·3
citrate	0·09	benzoate	2·7
malonate	0·4	lactate	5·9
malate	0·8	acetate	25·8

It is known that calcium can form association compounds with citrate and a number of other ions (Greenwald, 1938). The possibility of association with other organic anions was therefore also investigated (Johnston, 1956).

Conductivity-titration curves prepared for a tribasic (citric), a dibasic (malic), and a monobasic acid (mandelic), are shown in Figs 1 and 2. The curves show that at pH's near 4 there is considerable association with citric, less with malic, and little with mandelic. As mandelic brings a large amount of phosphate into solution association is obviously not a dominant influence with this acid. This is confirmed by the results in Fig. 3 in which the "Chelation Index" (Johnston, 1956) is plotted against phosphate released from calcium phosphate. The figure shows little correlation between the two factors.
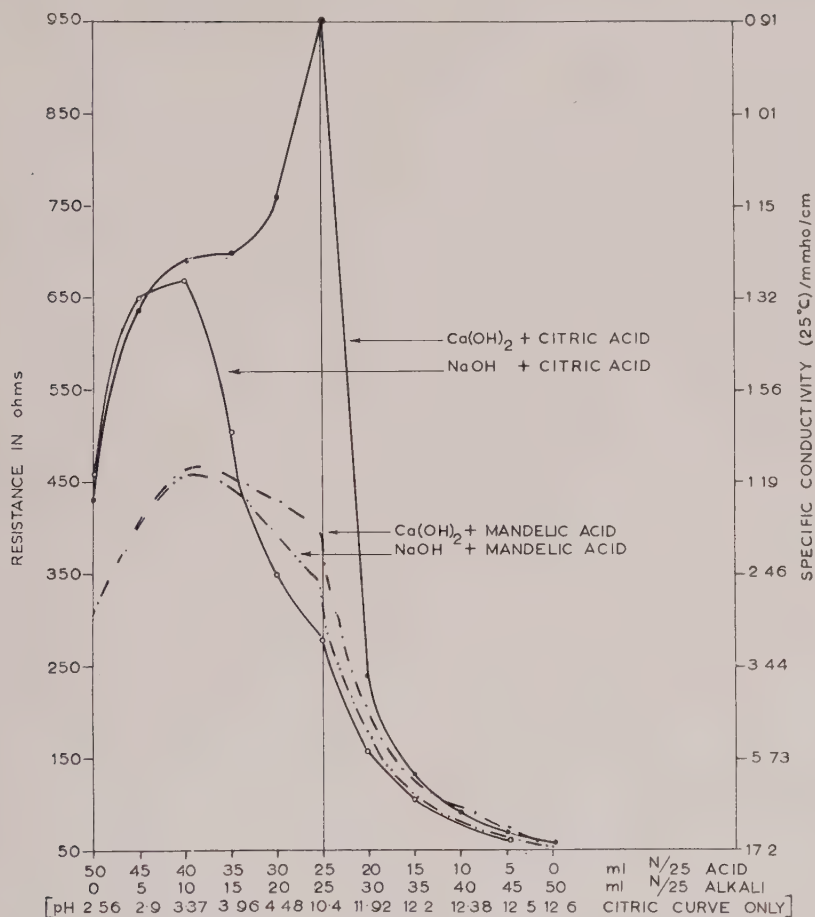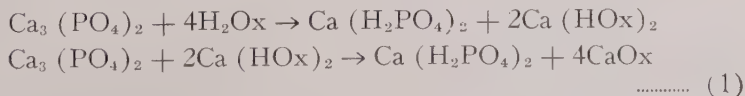
FIG. 1.—Conductivity-titration curves for citric acid and mandelic acid.

THE REACTIONS BETWEEN CALCIUM PHOSPHATE AND ORGANIC ACIDS

Calculations for Aliphatic Acids

The pH of the suspension of 1 gram of calcium phosphate in 30 ml of N/10 oxalic acid was found to be 4·14. From the equilibrium constants it may be calculated that the first H^+ of the oxalic acid will be completely dissociated at this pH, and the second one nearly half dissociated. Its reactions with calcium phosphate may be represented in an idealized form as follows (Ox = oxalate):

$$Ca_3(PO_4)_2 + 4H_2Ox \rightarrow Ca(H_2PO_4)_2 + 2Ca(HOx)_2$$
$$Ca_3(PO_4)_2 + 2Ca(HOx)_2 \rightarrow Ca(H_2PO_4)_2 + 4CaOx$$

.... (1)
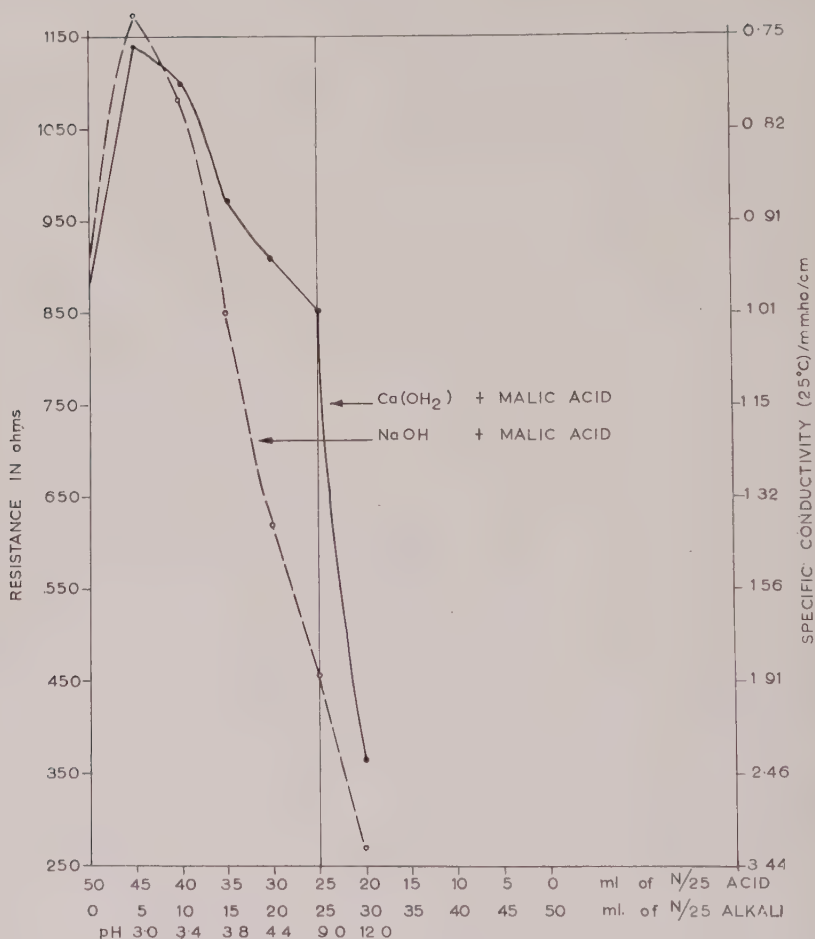
FIG. 2.—Conductivity-titration curves for malic acid.

Because of the effect of the insoluble calcium oxalate the reaction will go to completion and the amount of phosphate in solution will depend on the amount of acid added. It can be calculated from the equations that $N/10$ acid will release $355\,mg/100\,ml$ of P_2O_5 and in doing so will decompose $775\,mg$ of the calcium phosphate present. The analysis figure for P_2O_5 released was $323\,mg/100\,ml$. Similar calculations for other acids gave results similar to those obtained by analysis so it seemed likely that the results obtained could be explained on this basis.

The calcium phosphate used was Merck's G.R. calcium phosphate, tribasic. Analysis showed it to contain $38\cdot3\%$ Ca and $17\cdot6\%$ P and hence it has a composition corresponding to the formula $Ca_5\,(PO_4)_{2\cdot97}$ $(OH)_{1\cdot09}$. It is thus slightly more basic than hydroxyl apatite but not
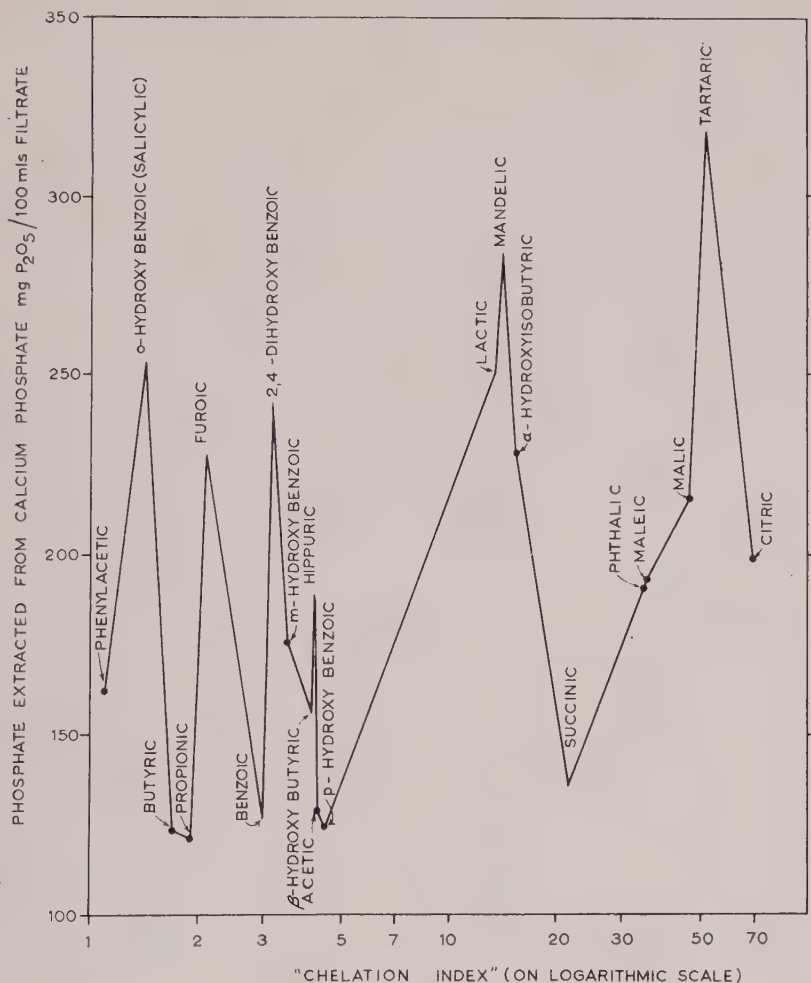
FIG. 3.—The relation between phosphate extracted from calcium phosphate by various organic acids and the "Chelation Index".

as basic as the material used by Mattson *et al.* (1951), which was $Ca_5 (PO_4)_{2 \cdot 88} (OH)_{1 \cdot 36}$. The reaction with oxalic acid may now be represented more accurately as:

$$2Ca_5 (PO_4)_3 OH + 7H_2Ox \rightarrow 3Ca (H_2PO_4)_2 + 7CaOx + 2H_2O$$

$$\dotsm (2)$$

From this reaction N/10 acid would be expected to bring 304 mg P_2O_5/100 ml into solution. For calculating the phosphate expected in solution from reactions with acid a correction must be made for the

water solubility of 26 mg P_2O_5/100 ml. This will come into solution before any acid reaction occurs and should be added. The loss of phosphate, which in water will be large compared with Ca, makes a minor correction to the composition of the phosphate necessary—it becomes $Ca_5 (PO_4)_{2.92} (OH)_{1.24}$—and the reaction with oxalic acid may be represented:

$$2Ca_5 (PO_4)_{2.92} (OH)_{1.24} + 7.08 H_2Ox \rightarrow 2.92 Ca (H_2PO_4)_2$$

$$+ 7.08 CaOx + 2.48 H_2O$$

.... (3)
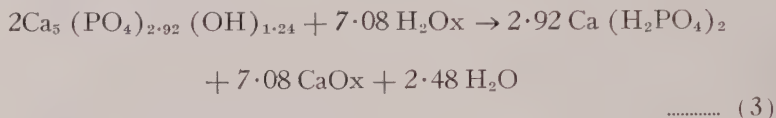
From this it may be calculated that 293 mg P_2O_5/100 ml will come into solution. The total will thus be 293 + 26, or 319 mg, which compares well with 323 mg found by experiment.

The water solubility of the phosphate (26 mg P_2O_5/100 ml at pH 6·1) is very high. It may be compared with the 0·6 mg/100 ml at pH 6·8 found by Mattson et al. (1951) for their more basic (lower phosphate) material. By treating their material with sodium phosphate Mattson et al. (1951) lowered its isoelectric point, lowered the pH of the water extract to 6·4, and increased the phosphate in solution sixfold to 3·7. This, together with a comparison of Figs 4, 5, and 6, indicates that the Merck material was prepared in a solution high enough in phosphate to produce a surface layer capable of releasing considerable phosphate to water. It may be considered as a phosphate very similar to that of Mattson's, but with a surface layer of adsorbed phosphate.

Calculations like that for oxalic acid were made for the other aliphatic acids used by Johnston (1954a). Unfortunately, pH was not determined in the original work so a number of the extractions were repeated. The lack of material made it impossible to repeat them all but the pHs were clearly related to the dissociation constants so that estimates were made for the other acids. The errors involved will be relatively small.

The calculations mere made on the basis of equation (3) or its equivalent for monobasic acids, and it was assumed that the dissolution reaction would only go as far as the acid dissociation would allow. Only in the case of oxalic acid was it assumed that the removal of calcium ions from solution would enable the reaction to go further.

The results are shown in Table 1 and generally they are reasonably close to the experimental figures. Those most in error are tartaric, citric, and malic acids with ratios of found to calculated values of over 130%. Lactic and succinic acids also differ considerably with percentages between 125 and 130. In these systems there is some mechanism removing ions from solution so that more acid can dissociate and more phosphate can come into solution. This mechanism may be precipitation of calcium salts (the list given shows the solubilities of most of them are low) or association (the "Chelation Indices" given in Table 1 show that these acids can form association compounds with calcium).

TABLE 1.—Calculated and Experimentally Determined Values for Phosphate Released from Calcium Phosphate by Various Aliphatic Acids.

Acid	pH	Dissociation constant	Dissociated (%)	P₂O₅ mg/100 ml		Found	Chelation Index
				Calculated	Found	Calculated (%)	
Oxalic	4·14	(1) 6.5×10^{-2} (2) 6.1×10^{-5}	100; 46	319	323	101	
Maleic	(4·2)	(1) 1.2×10^{-2} (2) 2.6×10^{-7}	100; 1	173	192	111	35·0
Pyruvic	(4·1)	3.2×10^{-3}	98	313	275	88	
Tartaric	(4·1)	(1) 1.3×10^{-3} (2) 6.9×10^{-5}	95; 47	235	318	135	
Citric	3·90	(1) 8.2×10^{-4} (2) 1.8×10^{-4}	87; 13	122	199	163	51·2
Furoic	(4·0)	7.6×10^{-4}	88	284	288	101	70·5
Mandelic	3·94	4.3×10^{-4}	79	258	284	110	2·1
Malic	4·00	(1) 4.0×10^{-4} (2) 9.0×10^{-6}	80; 8	156	215	138	14·2
Glycollic	(4·0)	1.5×10^{-4}	60	202	249	123	46·3
Lactic	(4·0)	1.4×10^{-4}	58	196	249	127	13·5
α–OH isobutyric	(4·1)	1.1×10^{-4}	58	196	228	116	15·4
Succinic	(4·2)	(1) 6.6×10^{-5} (2) 2.8×10^{-6}	51; 4	107	136	127	22·0
β–OH butyric	4·20	5.1×10^{-5}	45	158	155	98	4·2
Acetic	(4·35)	1.8×10^{-5}	30	114	129	113	4·3
Butyric	(4·4)	1.5×10^{-5}	27	106	123	116	1·7
Propionic	(4·4)	1.4×10^{-5}	26	102	121	119	1·9

The reasons for the calculated figures being generally lower than the experimental ones lies probably in an underestimation of the % dissociations of the acids in the systems which contain a solid phase and two salts as well as the acid.

Calculations for Aromatic Acids

A similar series of calculations was made for the aromatic acids studied by Johnston (1954b). The results are shown in Table 2. A new factor is involved in these—the solubility of the acids. Unlike the aliphatic acids most of the aromatic acids are too insoluble in water to make an N/10 solution. The systems were therefore made up by weighing out the calcium phosphate and the calculated amount of acid for an N/10 solution and then adding water and shaking.

In the calculations no allowance was made for the solubility, as in the conditions of these experiments the figures for solubility of the acids in water would not apply. The calculated figures, however, come reasonably close to those found by experiment although generally, unlike those for aliphatic acids, the ratio of found/calculated was less than 100%. It may be noted that where the differences were greatest (the three amino benzoic acids and hippuric acid) the solubility of the acid is low. An exception is phthalic acid in which the ratio of found/calculated is 112% despite a solubility of only 65% of N/10. Here it must be presumed that there is some removal of calcium ions from solution that enables more acid to come into the reaction.

The effect of the salts in the system on the acid dissociation noted in the aliphatic acid series would, of course, also apply to the aromatic acids, but here it is more than cancelled out by the solubility effect. The solubility effect is therefore rather greater than indicated in Table 2 and affects nearly all the acids to some extent, not only the most insoluble of them.

The Behaviour of Calcium

From Tables 1 and 2 it seems very likely that the phosphate is brought into solution from calcium phosphate by direct acid dissolution as shown in a general way in equations 2 and 3. The calculations proved reasonably accurate considering the differences between these systems and those from which the dissociation constants were derived.

Further support for this view was obtained from some calcium analyses (Table 3) done to investigate the mechanism of the removal of calcium ions from the systems in which the ratio of found/calculated was unduly high. From the equation
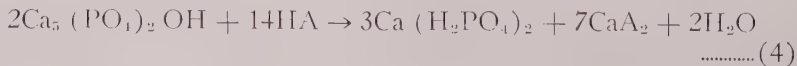
$$2Ca_5 (PO_4)_2 OH + 14HA \rightarrow 3Ca (H_2PO_4)_2 + 7CaA_2 + 2H_2O$$

$$............(4)$$

TABLE 2.—Calculated and Experimentally Determined Values for Phosphate Released from Calcium Phosphate by Various Aromatic Acids.

Acid	pH	Dissociation Constant	Dissociated (%)	Concentration of saturated solution (m.e. %)	P_2O_5 mg/100 ml Calculated	P_2O_5 mg/100 ml Found	Found Calculated (%)	Chelation Index
Phthalic	(4·1)	(1) $1·3 \times 10^{-3}$ (2) $3·1 \times 10^{-6}$	94	65	170	190	112	34·4
Salicylic	(3·8)	$1·06 \times 10^{-3}$	4	13	281	254	90	
2, 4, di-OH benzoic	3·82	$5·16 \times 10^{-4}$	87	15	252	242	96	3·2
Acetyl salicylic	(4·0)	$3·3 \times 10^{-4}$	77	55	252	221	88	
Hippuric	4·06	$2·3 \times 10^{-4}$	77	22	240	188	78	4·2
m-OH benzoic	(4·1)	$8·7 \times 10^{-5}$	73	67	181	176	97	3·5
Benzoic	(4·1)	$6·5 \times 10^{-5}$	52	22	158	127	80	3·0
Phenylacetic	4·13	$5·6 \times 10^{-5}$	45	100	152	162	107	1·1
Gallic	(4·3)	$4·0 \times 10^{-5}$	43	53	155	149	96	
p-OH benzoic	4·43	$2·9 \times 10^{-5}$	44	57	155	124	80	4·5
m-NH₂ benzoic	(4·6)	$1·6 \times 10^{-5}$	44	—	140	105	75	
p-NH₂ benzoic	4·66	$1·2 \times 10^{-5}$	39	22	131	100	76	
o-NH₂ benzoic	(4·7)	$1·1 \times 10^{-5}$	36	26	131	95	73	

Table 3.—The Phosphate and Calcium in Extracts of Calcium Phosphate with Various Acids.

Acid	PO₄ (m.e./100 ml)		Ca (m.e./ 100 ml)	Ca as Ca(H₂PO₄)₂ (m e./100 ml)	Ca as Ca(H₂PO₄)₂ (%)
Oxalic		13·6	4·0	4·0	100
Citric		8·2	6·8	2·2	32
Mandelic		11·9	11·8	3·5	30
Malic		8·8	7·1	2·4	34
β-OH butyric		6·6	5·6	1·7	30
2, 4, di-OH benzoic		10·3	10·0	2·9	29
Hippuric		7·8	7·6	2·1	28
Phenylacetic		6·8	6·0	1·8	30
p-OH benzoic		4·8	3·3	1·1	33
p-NH₂ benzoic		3·4	2·4	0·6	25
Hydrochloric 5 m.e.	pH3·92	13·9	13·0	4·1	31
3 m.e.	4·39	8·6	7·8	2·4	34
1 m.e.	4·97	3·3	2·6	0·6	33
0·5 m.e.	5·26	1·8	1·2	0·1	33
0	6·10	1·1	0	—	—

it is clear that one mol of calcium phosphate will produce 10 equivalents of calcium and 9 equivalents of phosphate. Three of the calcium equivalents are present as Ca $(H_2PO_4)_2$ and seven as the calcium salt of the acid used. The acid dissolution would follow a pattern like that of Fig. 4 adapted from the paper of Mattson et al. (1951). After phosphate treatment the curves changed (Fig. 5). These may be compared with curves from the Merck phosphate (Fig. 6).
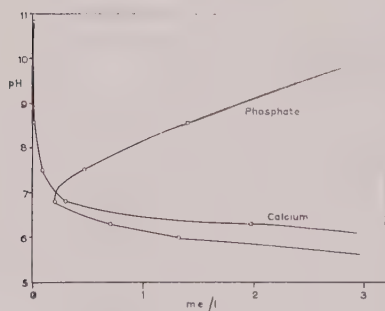
Fig. 4.—The calcium and phosphate solubilities of calcium phosphate in water as a function of pH. From Mattson et al (1951).
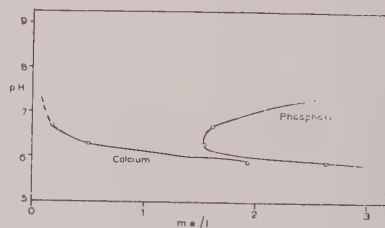
Fig. 5.—The calcium and phosphate solubilities of calcium phosphate after treatment with NaH₂PO₄. From Mattson et al (1951).

In Figs 5 and 6, surface effects are superimposed on the dissolution. Above pH 5, as Mattson *et al.* (1951) have described, the surface effects dominate the solubility properties of the systems, but around pH 4 the main effect is that of acid dissolution and surface effects are relatively small. A comparison of Figs 4 and 6 gives a measure of the extent of the surface effect and if the phosphate figures in Table 3 are corrected for it the amount of calcium associated with phosphate as Ca (H_2PO_4)$_2$ can be calculated (column 4). This should be 30% of the total calcium in solution if all the calcium salt of the acid is in solution. If there has been any precipitation it will be more than 30%. The percentages shown in Table 3 indicate clearly that all the calcium oxalate is precipitated but that the other calcium salts are in solution.

Fig. 6.—The calcium and phosphate solubilities of the calcium phosphate used as a function of pH. Note the change in scale.

As associated calcium would be included in the analyses it appeared that association is the mechanism removing calcium ions from solution in the system in which the calculated values were too low (citric, malic, tartaric, lactic, succinic, phthalic). Figures 1 and 2 discussed above show that near pH 4 citrate and malate can both form association compounds with calcium. Johnston (1956) gives a list of "Chelation Indices" for the acids used and these are shown in Tables 1 and 2. Although not obtained at pH 4 it is evident that the systems containing acid anions that can form association compounds with calcium are those in which the ratio found/calculated is high. It thus seems probable that association, not precipitation, is the cause of the abnormally high ratios.

DISCUSSION

In the earlier papers of this series (Johnston, 1952, 1954a, 1954b) the ability of acids to bring phosphate into solution from calcium phosphate was related to their structure. It was shown, for example, that a–hydroxy acids were more effective than the corresponding unsubstituted acids. Primarily this effect is one of acid strength—the stronger the acid the greater the dissolution—and the hydroxy-acids are, of course, stronger than the unsubstituted ones. Other than the effect of increasing the acid strength little evidence has been found that the hydroxy group has any specific effect on the reaction.

There is, however, a structural factor that does have a direct influence on the reaction and that is the presence of a second carboxyl group. The extra group, because it is generally only slightly dissociated, causes an overall fall in acid strength and a considerable reduction in the amount of phosphate brought into solution. This has tended to

mask is direct effect, which is a removal of calcium ions from the reaction products by association, thus allowing the reaction to go much further than is would with non-associating acids. The extent of this effect can be seen in the ratios found/calculated for the acids: citric, tartaric, malic, succinic, and phthalic. Malic acid is also able to associate calcium strongly at higher pHs but at pH 4·2 the second carboxyl group is so slightly dissociated that it is unlikely to react to any extent. Mandelic, lactic, and α–OH isobutyric can also combine with calcium at higher pHs, but as Fig. 1 shows, the amount associated falls with pH and for mandelic acid at least, is very small at pH 4.

CONCLUSION

It may be concluded that the reaction of organic acids with calcium phosphate is one of acid dissolution, the amount of phosphate released depending primarily on the strength of the acid. When dibasic acids and a tribasic acid (citric) are used, a secondary effect appears due to the ability of these acids to form unionized association compounds with calcium and remove calcium ions from solution. This makes the reaction go further and increases the phosphate brought into solution.

The relationship between the amount of phosphate dissolved and the acid structure considered in earlier papers of this series (Johnston, 1952, 1954a, 1954b) is thus clarified. There are two effects operating. The first is the effect of substituted groups, such as α–hydroxy, β–hydroxy, α–keto, and hydroxy and amino groups in the benzene ring, which alter the strength of the acid. The second is the effect of a second carboxyl group which by association removes calcium ions and allows the reaction to go further than would be expected on the basis of acid strength alone.

REFERENCES

GREENWALD, I., 1938: The Dissociation of Some Calcium Salts. *J. biol. Chem. 124* : 437-52.

JOHNSTON, H. W., 1952: The Solubilization of Phosphate, I. The Action of Various Organic Substances on Dicalcium and Tricalcium Phosphates. *N.Z. J. Sci. Tech. 33B* : 436-46.

————, 1954a: The Solubilization of "Insoluble" Phosphate, II—A Quantitative and Comparative Study of the Action of Selected Aliphatic Acids on Tricalcium Phosphate. *N.Z. J. Sci. Tech. 36B* : 49-55.

————, 1954b: The Solubilization of "Insoluble" Phosphate, III—A Quantitative and Comparative Study of the Action of Chosen Aromatic Acids on Tricalcium Phosphate. *N.Z. J. Sci. Tech. 36B* : 281-4.

————, 1956: Chelation between Calcium and Organic Anions. *N.Z. J. Sci. Tech. 37B* : 522-37.

MATTSON, S; KOUTLER-ANDERSSON, E.; MILLER, R. B.; VAHTRAS, K., 1951: Phosphate Relationships of Soil and Plant, VIII. Electrokinetics, Amphoteric Behavior and Solubility Relationships of Calcium Phosphates. *Ann. Roy. Agr. Coll. Sweden, 18* : 128-53.

SEIDELL, A., 1940: "Solubilities of Inorganic and Metal-organic Compounds." D. van Nostrand Co. Inc., New York.

OBSERVATIONS ON THE FOOD OF THE HEDGEHOG
(*Erinaceus europaeus* L.) IN NEW ZEALAND

By ROBERT E. BROCKIE, Animal Ecology Section, Department of
Scientific and Industrial Research, Wellington

Summary

Ten stomachs and 90 droppings of hedgehogs mainly from the Wellington
province have been examined; food items present in the stomach were also
detected in the rectal faeces. The main food items in suburban areas are slugs
and millipedes although snails are frequently eaten. The main items of food on
pasture land are slugs and moth caterpillars while in the sand dunes north of
Paekakariki snails, millipedes, and frogs are the main foods.

Beetles and spiders are frequently eaten but seldom contribute much to the
bulk of the diet. Other items, such as earthworms and cicada nymphs are less
important although they may be taken in numbers during certain seasons. A
substantial amount of plant matter is ingested with the food but it appears that
small leaves and buds of clover are the only plant material intentionally sought
after. Millipedes and slugs are eaten throughout the year, snails most frequently
during the spring and moth larvae most frequently during the autumn.

Fragments of shell appear in faeces of captive animals fed on eggs, however,
no egg shell was found in the droppings of wild hedgehogs; the significance of
hedgehogs as predators of ground nesting birds is discussed.

INTRODUCTION

The European hedgehog (*Erinaceus europaeus* L.) was introduced to
the South Island of New Zealand in the 1870s and into the North Island
about 1910. The animal subsequently spread widely and became abun-
dant in most suburban districts and more sparsely distributed in farm-
ing country, scrub, and forest (Wodzicki, 1950, p. 58-59). It was not
long before the hedgehog was accused of being a menace to ground
nesting birds, especially pheasants, quail, duck, pipits, and skylarks.
It was even thought that the animal was responsible for a decline in the
numbers of these birds. Such was the outcry for them by Acclimatiza-
tion Societies throughout the country. During this period 53,647 snouts
were submitted for the bounty in the North Island alone (Wodzicki,
1950, p. 63).

A certain amount of work has been done in Europe on the food of
the hedgehog but systematic observations on stomach contents or drop-
pings appear to be confined to the Eastern hedgehog, *E. roumanicus,*
the long-eared hedgehog, *Hemiechinus auritus* (Bate, 1904; Herter,

1938; Bibikov, 1957) and the Chinese hedgehog, presumably *E. dealbatus* (Ch'eng-Chao Liu, 1937). It is somewhat surprising that no systematic analysis of hedgehog food has been made in Great Britain or Western Europe. Barrett-Hamilton and Hinton (1910-21) critically examined and collated scattered observations and anecdotes reported in British journals on natural history and zoology of the nineteenth century. Later Ritchie (1931) and Lancum (1947) commented on the hedgehog diet and Lindemann (1951) and Cott (1951) have made observations on the choice of food and the palatability of birds' eggs using hedgehogs in the laboratory as experimental animals.

The general picture that emerges from these studies is that hedgehogs will eat any protein food that they chance upon, particularly beetles, grubs, snails, slugs, pupae, maggots, frogs, lizards, rats, young rabbits, snakes, carrion, and occasionally young birds or birds' eggs. They are also reported as having eaten grapes, apples, and oats. It is widely believed in Europe that the hedgehog is innocuous and that the losses caused by the occasional rifling of a hen house or bird's nest are outweighed by the animal's capacity for eating garden pests. However, no details are available as to which, if any, are the main or preferred foods.

Previously no attempts have been made to study the food of New Zealand hedgehogs although Wodzicki (1950, p. 60), in response to a questionnaire sent to 122 stock inspectors and naturalists about the economic status of the animal, found that it was generally believed that local hedgehogs eat the same food as English ones although many of his informants gave evidence of their attacking poultry and game birds' eggs. Bull (1953) saw a hedgehog eating the contents of a skylark's nest at Mangere, Auckland.

Because of the lack of precise information the following investigation, based on the analysis of the contents of hedgehog stomachs and droppings, was begun.

MATERIALS AND METHODS

The contents of 10 stomachs, 5 of which were empty, and 90 droppings were examined, and observations made on the feeding habits of several wild and captive animals. Droppings were collected throughout the year but during winter, when most of the animals were hibernating, only 5 were found. Most of the droppings and all the stomachs were collected in the southern half of the North Island. Three droppings were collected at Stoke, Nelson; and another one at Kawhia. Half of the droppings were collected on the grass and scrub-covered sand dunes two miles north of Paekakariki, an area which is known to support a dense hedgehog population. These dunes are clothed in places with thick scrub and lupins that provide abundant cover for invertebrates (Brockie, 1957). Twenty-two of the droppings were collected in the outskirts of towns and are listed in Table 1 as being found in "suburbs".

Most of these were from public parks or domestic gardens. Thirteen droppings were collected from open pasture land, usually where sheep were being grazed. Eight came from a country orchard at Marton and 2 were collected in native forest at 2,000 ft in the Rimutaka mountains.

In the early stages of this investigation it was proposed to examine stomach contents only, but it soon became apparent that droppings were almost as useful. A comparison between the stomach contents and the faeces of several animals revealed that all items identifiable in the stomach were also recognizable as indigestible fragments in the lower rectum. However, more quantitative data can be obtained from stomach analyses than from droppings because the food items in the stomachs are generally whole. Well fed, captive hedgehogs defaecate at least two or three times a night and the droppings are cylindrical, between 1 and 2 inches long, and about the thickness of a pencil. They are black or dark green in colour and often contain beetle elytra or millipede fragments which are readily visible to the naked eye. During wet weather they soon break up and disappear, but they may lie on the ground for more than a week if conditions are dry. Droppings are difficult to find in scrub or long grass, especially during the summer months, but a regular search of grazed pasture, suburban lawns, or of paths and dry gutters near hedges or shrubberies is usually successful.

The droppings were usually dry when collected. They were broken apart with forceps in a petrie dish half full of water and examined under a binocular microscope before the remains were identified. Where identification was obscured by turbidity, the droppings were washed with water on a fine sieve.

RESULTS OF ANALYSES

General

A quantitative analysis of the substances in the droppings was impossible because of the fragmentary nature of many of the remains. Instead, each item in any particular stomach or dropping was, on analysis, given a number which expressed roughly the amount which it contributed to the bulk of the dropping. Results of the analyses are shown in Tables 1 and 2.

In Table 1, with the exception of items believed to be eaten, accidentally, the food substances discussed below are arranged from left to right in order of their frequency of occurrence. For classification (1-5) under "amount", 1 indicates a trace, 2 a small amount, 3 a moderate amount, 4 a large amount, and 5 that the dropping contained only that substance. No difficulty was experienced in allocating food substances to class 1 or class 5. Where half the contents of a stomach or dropping consisted of one item, that item or substance was classed as 3. Classes 2 and 4 were used to accommodate other amounts excluded from classes 1, 3, and 5.

TABLE 1.—Results of Analyses of 90 Hedgehog Droppings.

Habitat	Amount	Slugs	Beetles (Coleoptera)	Millipedes (Diplopoda)	Snails (Helix aspersa)	Earthworms (Lumbricus terrestris)	Moth grubs (Lepidoptera larvae)	Earwigs (Dermaptera)	Spiders (Araneidae)	Frog (Hyla aurea)	Beetle grubs (Coleoptera larvae)	Moths (Lepidoptera adults)	Unidentified insect pupae
Dunes (45 droppings examined)	*												
	5	—	—										
	4	—	—	6	4		1			4			
	3	2	2	3	5	4	2	5		2	2		
	2	3	5	—	9	3	2	6	1	6	2	2	
	1	4	7	7	8	17	3	4	9	2	3	1	2
Total		9	14	19	26	24	8	15	10	14	7	3	2
% occurr.		20	31	42	57	53	18	33	22	31	15	7	4
Suburbs (22 droppings examined)	5	—	—	—	—	—	—	—	—	—	—	—	—
	4	2	—	3	1	—	—	—	—	—	—	—	—
	3	5	1	3	3	—	2	—	—	—	—	—	—
	2	2	3	—	1	2	2	1	1	—	—	—	2
	1	4	5	3	—	2	1	2	2	—	1	6	3
Total		13	9	9	5	4	5	3	3	—	1	6	5
% occurr.		59	41	41	23	18	23	14	14	—	5	—	23
Pasture (13 droppings examined)	5	1	—	—	—	—	2	—	—	—	—	1	—
	4	1	—	—	—	—	2	—	—	—	1	—	1
	3	1	—	—	—	—	—	—	—	—	—	—	1
	2	3	1	2	—	—	4	—	1	—	—	1	—
	1	3	3	1	1	3	2	2	3	—	1	—	2
Total		9	4	3	1	3	10	2	4	—	2	2	4
% occurr.		69	31	26	8	26	78	15	31	—	15	15	31
Orchard (8 droppings examined)	5	—	—	—	—	—	—	—	—	—	—	—	—
	4	—	—	—	—	—	—	—	—	—	—	—	—
	3	—	—	—	—	—	1	—	—	—	—	—	—
	2	3	3	—	—	—	2	1	—	—	2	—	1
	1	2	2	—	—	—	1	1	2	—	1	1	—
Total		5	5	—	—	—	4	2	2	—	3	1	1
Native Forest (2 droppings examined)	5	—	—	—	—	—	—	—	—	—	—	—	—
	4	—	—	2	—	—	—	—	—	—	—	—	—
	3	—	—	—	—	—	—	—	—	—	—	—	—
	2	—	1	—	—	—	—	—	—	—	—	—	—
	1	—	1	—	—	—	1	—	—	—	1	—	—
Total		—	2	2	—	—	1	—	—	—	1	—	—
Total No. of occurrences		36	34	33	32	31	28	22	19	14	14	12	12
No. of occur. as % of total		40	37	37	36	35	31	24	21	15	15	13	13

TABLE 1.—*Continued.*

Flies (Diptera)	Unidentified Insect Remains	Woodlice (Porcellio scaber)	Ants (Formicoidea)	Bees and Wasps (Hymenoptera)	Wetas (Orthoptera)	Cicada adults	Cicada nymphs	Mites (Acarina)	Maggots (Diptera larvae)	Grass leaves and roots	Misc. plant fragments	Clover leaves and buds	Hair	Seeds
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	2	—	—	1	2	—	—	—	3	—	—	—	—
—	2	—	—	—	1	1	—	—	—	11	1	—	—	3
3	5	3	2	4	1	2	2	2	—	5	9	6	10	4
3	7	5	2	4	3	5	2	2	—	19	10	6	10	4
7	15	11	4	9	7	11	4	4	—	42	22	13	22	15
—	—	—	—	—	—	—	2	—	—	1	2	—	—	—
—	—	1	—	—	—	—	1	—	1	2	1	—	—	—
1	—	—	1	—	1	—	1	—	1	3	1	—	—	—
2	4	1	2	1	—	—	—	3	1	4	3	3	2	5
3	4	2	3	1	1	—	3	3	2	10	7	3	2	5
14	18	9	14	5	5	—	14	14	9			14	9	23
—	—	1	—	—	—	—	—	—	—	—	1	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	1	—	—	—	—	3	1	—	—	—
2	—	—	2	1	—	—	—	—	—	4	—	2	—	1
2	—	1	2	1	1	—	—	—	—	8	1	2	—	1
15	—	8	15	8	8	—	—	—	—	61	8	15	—	8
—	—	—	—	—	—	—	—	—	—	—	1	—	—	—
—	—	—	—	—	—	—	—	—	—	3	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	1	—	—	—
4	—	2	2	—	—	—	—	—	—	4	5	6	2	1
4	—	2	2	—	—	—	—	—	—	7	7	6	2	1
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	1	—	—	—
—	—	—	—	—	—	—	—	—	—	—	1	—	—	—
12	11	10	9	6	5	5	5	5	2	44	26	17	14	14
13	12	11	10	7	5	5	5	5	2	49	29	19	15	15

*5 indicates that the dropping contained only the one substance; 4, a large amount of the substance; 3, a moderate amount; 2, a small amount; 1, a trace.

The above method was inadequate for classifying earthworm remains because the chaetae are so small that their bulk fails to give a true picture of the importance of this item and does not reveal differences in the numbers of earthworms eaten.

A wet sample of two grams of faeces was diluted in water and the chaetae counted individually. To make this figure comparable with others in Table 1, the following conversion table was used:

$$1 \text{ to } 25 \text{ chaetae} = \text{grade } 1 \text{ (trace)}$$
$$25 \text{ to } 50 \text{ chaetae} = \text{grade } 2 \text{ (small amount)}$$
$$\text{over } 50 \text{ chaetae} = \text{grade } 3 \text{ (moderate amount)}$$

Only the more frequently occurring species in the droppings and stomachs have been identified, but as all the material is preserved in alcohol at the Animal Ecology Section, D.S.I.R., Wellington, complete identification can be attempted in the future should it become necessary. With the exception of vegetable remains and other substances thought to have been eaten accidentally with normal food, each item of food is arranged in Table 1 from left to right according to the frequency with which it occurred in the stomachs and droppings.

Table 2 summarizes details on seasonal variations in the amounts of the main food substances.

Notes on the Food Substances

SLUGS

These were represented in droppings by small internal shells, radulae, and by occasional shreds of muscular tissue and skin. Faeces from hedgehogs that had eaten many slugs were of a liquid consistency and when viewed under the microscope appeared to include much bile-stained slime. Forty per cent. of the droppings contained slug remains, those from suburban gardens and pasture land containing them most frequently—especially during the summer months when they occurred in 56% of the droppings. Faeces taken from the rectum of one hedgehog contained 25 slug radulae, but this was an unusually large number.

The Grey Field Slug, *Agriolimax reticulatus*, is one of the commonest species in the southern part of the North Island and this appears to be the one most frequently eaten; however, the hedgehog will eat any other species available. One animal was seen eating a native slug, *Athoracophorus bitentaculatus*, in native forest at Point Howard, Wellington.

ADULT BEETLES (Coleoptera)

These were represented by chitinous fragments in the droppings. Thirty-seven per cent. of the droppings contained some fragments but remains were never so abundant as to form the bulk of any dropping. Bettles were eaten in all types of habitat throughout the year, most frequently during the summer months. These insects were never more than three-quarters of an inch long, though E. Dawson (pers. comm.,

Table 2.—Details of Seasonal Variations in the Amounts of Main Foods of Hedgehogs.

Season	Amount	Slugs	Beetles	Milli-pedes	Snails	Earth-worms	Moth larvae
SPRING (Sept.-Oct.)	5	—	—	2	—	—	—
	4	—	—	5	4	—	—
31 in sample	3	3	1	3	4	3	1
	2	3	5	—	5	3	2
	1	5	5	8	8	14	1
Total		11	11	18	21	20	4
(%)		30	32	60	66	63	14
SUMMER (Nov.-Mar.)	5	1	—	—	—	—	1
	4	1	—	2	—	—	1
30 in sample	3	4	2	2	4	—	2
	2	6	6	—	2	—	3
	1	5	8	2	1	4	4
Total		17	16	6	7	4	10
(%)		47	48	20	22	12	28
AUTUMN (Apr.-May)	5	—	—	—	—	—	2
	4	1	—	4	1	—	2
24 in sample	3	1	—	1	—	1	2
	2	2	2	2	3	2	5
	1	2	3	1	1	4	2
Total		6	5	8	4	7	13
(%)		17	15	27	12	22	46
WINTER (June-Aug.)	5	—	—	1	—	—	—
	4	1	—	—	—	—	—
	3	—	—	—	—	—	—
5 in sample	2	—	—	—	—	—	—
	1	1	2	—	—	1	1
Total		2	2	1	0	1	1
(%)							

1957) observed that gravid female huhu beetles, *Prionoplus reticularis*, appeared to form a large part of the hedgehog's diet during midsummer in a pine wood close to Auckland. He noted that hedgehogs took large numbers of male huhus that had been attracted to females in cages within the forest. The hedgehogs removed the abdomen from the remainder of the body (including the elytra) and, after the fatty contents of the body were removed, often rejected the integument as well. J. H. Sorensen (pers. comm., 1956) examined several hedgehog droppings from the Dunedin district and found that they consisted largely of beetle elytra and legs.

No attempt has been made to identify all the species found, however; *Oemona hirta* occurred frequently in droppings from the dunes and *Pyronota festiva* was recorded in one of the droppings from the Rimutaka mountains.

Millipedes (Diplopoda)

These were identified from the numerous characteristic body segments and legs which resisted digestion. Thirty-seven per cent. of the droppings contained some millipede fragments and several contained nothing else, especially during the spring and autumn months. Large numbers were eaten in the sand dunes and in the suburbs but few on pasture land. Two of the commonest millipedes round Wellington are *Cylindroiulus brittanicus* and *Ophiulus pilosus* (E. Dawson; pers. comm.). These species seldom exceed three-quarters of an inch in length but are extremely abundant and ubiquitous in leaf and grass litter throughout the year. The fragmentary remains in the droppings could not be identified specifically but the two common species were probably the most frequently eaten. These millipedes are equipped with scent glands which emit a strong pungent odour that could be easily detected by hedgehogs at night, and it is likely that this is another reason why millipedes are so frequently found and eaten.

The two droppings collected in native forest consisted almost entirely of millipede remains—a large native millipede which has not been identified.

Snails

Several hedgehogs were kept in captivity for two or three days and fed exclusively on the common Garden Snail, *Helix aspersa*. The hedgehogs invariably crushed the shells to small pieces before eating the animal inside, but some large snails were too strong and resisted the determined grappling of two adult animals. Fragments of shell were always ingested with the snails and were easily identified subsequently in the droppings. The faeces of hedgehogs that had recently eaten snails contained radulae, shreds of skin, and quantities of bile-stained slime. Occasionally, the calcareous copulatory dart was also found.

Of the 90 droppings examined, 32 (36%) contained snail remains. Fifty-seven per cent. of the droppings from the sand dunes contained snails, many of them in moderate or large amounts. Snails were also found in 23% of the suburban droppings but in only one of the thirteen collected on pasture land (this difference is statistically significant). There were none in the samples from orchard or native forest.

Snails were most frequently eaten during the spring months—few during summer and autumn. With the exception of an unbroken shell of a fresh water snail, *Limnaea* sp., *Helix aspersa* was the only snail found. Two hedgehogs in native forest at Point Howard, Wellington, were seen devouring the native snail *Wainuia urnula*. Dr R. Cumber, Entomology Division, D.S.I.R. (pers. comm., 1957) mentioned that hedgehogs are suspected of eating the large native snail, *Paryphanta traversii*, in a forest reserve near Levin.

EARTHWORMS (Lumbricidae)

In the droppings the only indication that hedgehogs had fed on earthworms was the presence of chaetae. It is not possible to identify worms from these chaetae alone, but as *Lumbricus terrestris* is the only common species in the Wellington area, this was assumed to be the main one eaten.

Thirty-five per cent. of all the droppings contained chaetae, those from sand dunes containing them most frequently. A few were also present in droppings from pasture land and from the suburbs.

MOTH CATERPILLARS

The chitinous outer skin, legs, head capsule, and jaws resisted digestion and were found in the droppings, although the hedgehog often had bitten off the head capsule before eating the grub. Of the 90 droppings examined 28 (31%) contained remains of lepidoptera larvae and most of these were found in late summer and autumn. Although a few remains were found in droppings from the sand dunes and suburbs, they were most frequently found in those from pasture land. Two droppings from the Orui sheep station in south eastern Wairarapa consisted almost entirely of a caterpillar, an army worm, *Pseudoletia seperata*, of which there was a plague at the time of collection.

EARWIGS (Dermaptera)

Twenty-four per cent. of the droppings contained earwig remains—mostly from the dune area but a few also from suburbs, pasture, and orchard. Two species were eaten: the native earwig, *Anisolabis littorea*, in the dunes, and the introduced earwig, *Forficula auricularia*, in the suburbs. Hedgehogs were liberated at Alexandra, Otago, in 1925 in order to control introduced earwigs in the orchards. Subsequently the earwigs became less common but it is unlikely that hedgehogs were entirely responsible for the decline (Dr D. Miller, pers. comm.).

SPIDERS (Araneidae)

Although spider fragments were frequently present (21%) in the droppings, they never occurred in large numbers, and it is unlikely that they contribute much to the hedgehog's diet. No large spiders were found.

AUSTRALIAN GREEN FROG (*Hyla aurea*)

These were represented by scraps of tough skin and shreds of muscular tissue. Only one dropping contained frog bones so it seems likely that hedgehogs eat only the belly and more fleshy parts, leaving the head and skeleton. Frogs were found only in the droppings of animals from the sand dunes north of Paekakariki, where the nearby marshes support large numbers. Two hedgehogs were found eating frogs alive and the cries of other captured frogs were heard frequently among the undergrowth and scrub near the marshes at night.

BEETLE LARVAE (Coleoptera)

Fifteen per cent. of the droppings contained remains of beetle larvae but these were seldom present in large numbers. One dropping examined in 1950 by the Entomology Division, D.S.I.R., consisted largely of a common grass grub, *Costelytra zealandica*.

MOTHS (Lepidoptera)

Tattered fragments of moth wings withstood digestion and were present in 13% of the droppings, usually in very small amounts. One exception was that of a dropping from the Orui sheep station in south-east Wairarapa and this consisted entirely of wings belonging to the adults of the army worm, *Pseudoletia seperata,* which were emerging in large numbers at the time of collection.

INSECT PUPAE

Present in 13% of the droppings, but as they were broken into very small pieces these could not be identified: many were probably the remains of blowfly larvae.

FLIES (Diptera)

Thirteen per cent. of the droppings contained wings or legs of flies—either blowflies, Fam. *Tachinidae,* or the housefly (*Musca domestica*). It might be mentioned that a number of the droppings were fly-blown.

WOODLICE (*Porcellio scaber*)

Calcareous body segments and legs withstood digestion and were present in 11% of the droppings—usually in small amounts. A few were found in those from dunes, suburbs, pasture, and orchard. Considering the abundance and ubiquity of the species (for it is probably the commonest large invertebrate to be found abroad at night on the ground), it is surprising that so few are eaten. They may be unpalatable to hedgehogs.

ANTS (Formicoidea)

The few ants found in the droppings were probably eaten accidentally with other food.

BEES AND WASPS (Hymenoptera)

Found in 8% of the droppings and always in small numbers. It is difficult to imagine how hedgehogs would catch active bees and wasps, and probably the few found here were dead or comatose when eaten.

WETAS (Orthoptera. Fam. Henicidae)

Five per cent. of the droppings contained weta remains. One of these was identified as *Hemiandrus* sp. but others were unidentifiable. J. Edwards (pers. comm., 1957) found remains of wetas in hedgehogs' stomachs near Auckland.

CICADA ADULTS AND NYMPHS

Adult cicadas were represented by fragments of wings and legs—no body segments or head parts were found—and nymphal cicadas by soft body segments and legs. *Melampsalta cingulata* was eaten in the suburbs and *M. cruentata* in the sand dunes. Both species are abundant in the Wellington district.

MITES (Acarina)

Most of the mites found on or among droppings were probably contaminations and had not been eaten by hedgehogs. Oribatid, Mesostigmatid, and Tyroglyphid mites were found.

GRASS ROOTS AND LEAVES: MISCELLANEOUS PLANT REMAINS

These appeared to pass through the alimentary canal unchanged and often formed the bulk of the droppings. Small leaves, twigs, scraps of bark, and thistle spines were found. One dropping consisted largely of the remains of an apple while another had a large piece of plum skin in it.

CLOVER LEAVES AND BUDS

Nineteen per cent. of the droppings contained clover leaves and buds in small quantities. They were always young leaves and succulent tips —never large leaves—indicating that the hedeghogs had intentionally selected and eaten them. Some confirmation of this point comes from Dr P. D. Sears, Grasslands Division, D.S.I.R., who mentioned that special fences had to be erected at Massey Agricultural College to protect experimental clover plants from being eaten by hedgehogs.

HAIR

Short pieces of hair were found in 15% of the samples. The hair, which was always that of hedgehogs, was probably ingested while the animals were grooming themselves. One exceptional dropping consisted of more than 500 hedgehog spines. As most of these had been pulled out by the roots it seems likely that the animal had been feeding on the rotting carcass of another hedgehog.

SEEDS

Fifteen per cent. of the droppings contained seeds but these were never present in large numbers. Grass and clover seeds were the commonest but it is unlikely that these were eaten on purpose. Wheat and barley were offered to several hungry hedgehogs but they refused to eat any.

Availability of Food

Ideally, a study of hedgehog food would combine an analysis of stomachs and droppings with extensive measurements of the stock of food available from various habitats. This was not possible in the present study but some observations were made on the food substances. With the exception of slugs and snails, these observations are based on general impressions gained in the field—not on quantitative studies.

The availability and abundance of hedgehog food appear to depend on three main factors: the habitat, seasonal fluctuations in the weather, and on the habits of many invertebrates.

In settled districts throughout the Wellington district the leaf litter from wind-breaks, shrubberies, domestic gardens, and hedges provides moist cover for many large invertebrates such as slugs, millipedes, beetles, moths and their larvae. Where lime is present in the soil and there is suitable cover, as in most domestic gardens and in coastal sand dunes, snails are plentiful, and these places provide hedgehogs with a varied diet in one form or another the year round.

Lowland sheep and cattle pastures support large numbers of slugs and moth and beetle larvae while cattle droppings themselves contain a wide variety of invertebrates suitable for hedgehog food. Hill pasture is usually strewn with the relics of old forest fires. Underneath these logs and stumps, slugs, moth and beetle larvae are plentiful and provide a good diet for hedgehogs. Observations in bush clad areas round Wellington city indicate that although native forests produce deep litter and support large populations of mites, springtails, and sandhoppers, it does not provide cover for many large invertebrates for hedgehogs to eat. Some ground living millipedes, beetles, spiders, and native slugs and snails occur, but rarely in large numbers. On the central volcanic plateau of the North Island the cover of tussock and *Dracophyllum* does not support many suitable invertebrates, but where towns have sprung up as at Taupo, Waiouru, and Turangi, slugs and snails have appeared. It is interesting to note, while travelling by car through the district, that the only dead hedgehogs seen on the roads are in townships or near the cultivated land surrounding them.

The climate of lowland areas of the North Island is milder than in Europe; snow seldom lies long on the ground and frosts are usually shortlived. As a result, many invertebrates, such as slugs and millipedes, which in Europe almost disappear during winter, can be found in moderate numbers throughout the year, but are not always available as they, like the hedgehogs, may aestivate in midsummer and hibernate in winter. A survey in the lupin-covered sand dunes north of Paekakariki revealed that during August, when most of the hedgehogs were hibernating, there were between eight and ten thousand snails and between 25,000 and 35,000 slugs to the acre. Seasonal flushes of emerg-

ing moth, beetle, and cicada larvae provide occasional rich sources of food for hedgehogs. During the autumn, army worms are available on dry pasture land and concentrations of these and other invertebrates may attract hedgehogs to the locality and so give rise to reports of hedgehog "swarms".

Many animals that are usually inaccessible to hedgehogs become vulnerable when they emerge to feed at night or to metamorphose; for instance, many grass grubs, earth-worms, and cicada larvae. On the other hand, slugs and snails avoid capture by climbing the stems of tall plants at night.

The grasshopper, *Phaulacridium marginale,* swarms among the sand dunes during late summer and autumn but none was found in the droppings of hedgehogs from that area. These grasshoppers appear to be able to detect the approach of an intruder even at night and avoid capture by quickly jumping out of the way.

Sandhoppers (*Talorchestia* spp.) and woodlice (*Porcellio scaber*) were very abundant in a wide range of habitats, yet they appeared to have been almost completely ignored by hedgehogs. Crushed woodlice and sandhoppers were offered to hungry captive hedgehogs but they were not eaten, so it seems that they are unpalatable.

DISCUSSION

In interpreting Tables 1 and 2 the amount of each substance and the size of the species involved must be taken into account when considering the frequency with which it occurs. Thus slugs, snails, and earwigs occur frequently and in large amounts, and as these animals are large they can be regarded as major items in the hedgehog's diet. Beetles and spiders are listed frequently in the tables but never in large amounts and as the species represented are small they cannot be regarded as important. On this basis, the main food items on pasture land are slugs and moth caterpillars; in the sand dunes snails, millipedes, frogs, and earwigs; in suburbs slugs and millipedes.

Exactly how far these results apply to other areas of New Zealand is not known, but conditions in the suburbs and sand dunes of Wellington are not radically different from suburbs and dunes in other parts of the country, so that observations on the diet of animals from these habitats in Wellington probably apply to other similar areas. However, the conclusions drawn from observations on droppings from pasture land in the Wellington province may not apply to other areas because of the different climate of the far north and south of New Zealand, resulting in a different species representation being available to hedgehogs in those places.

Twenty of the droppings examined in this study were collected in areas where, and during the season when, skylarks (*Alauda arvensis*), pheasants (*Phasianus colchicus*), and pipits (*Anthus novaeseelandiae*) were nesting, but no chips of egg shell were found in the faeces. Some caged hedgehogs were offered domestic hens' eggs but they made no

attempts to break them open or to eat them. Even though eggs were broken before their eyes and the animals greedily ate the contents, they never learnt to smash them open themselves although given every opportunity. Fragments of shell were frequently seen in the droppings from the animals that had eaten broken fowls' eggs and had any been present in the faeces of wild animals, they would probably not have been overlooked.

It has been claimed that hedgehogs are largely responsible for reducing the numbers of skylarks and ground nesting game birds in New Zealand, but there is no evidence to support this view. Odd reports of hedgehogs attacking birds' nests in this country have been published (Bull, 1953, Wodzicki, 1950, p. 60), but more intensive investigations on game birds reveal that these isolated incidents have a negligible effect on those bird populations studied. Westerskov (1955) concluded from a detailed survey of nest and brood mortality among New Zealand pheasants that only $0 \cdot 3\%$ of the known nests were destroyed by predators—harrier hawks (*Circus approximans*) and rats (*Rattus* spp.) being responsible. G. Williams (pers. comm., 1957) has made an extensive survey of chukor (*Alectoris graeca*) and quail (*Lophortyx california*) in this country and has not found direct evidence of nests being attacked by hedgehogs. Balham (1949) kept 35 grey and mallard ducks' nests under observation at Himatangi and found that none was disturbed by hedgehogs. In Britain, Middleton (1935) found that of 1323 partridge (*Perdix perdix*) nests under observation, 16 (or $1 \cdot 3\%$) were disturbed by hedgehogs. However, Axel (1956) found that hedgehogs were probably the main predator of the common tern (*Sterna hirundo*) which breeds in colonies at the Dungeness Bird Reserve, Kent, England. The loss of terns' eggs here was high until three hedgehogs were captured near the ternery and a low wire netting fence built to surround the area. It is interesting to note that the sand dunes on the south-west coast of the North Island harbour large numbers of skylarks and pheasants, yet there is a dense hedgehog population in the area.

Because no quantitative observations appear to have been made on the food of hedgehogs in Britain or in Western Europe, exact comparisons between New Zealand and these places cannot be made. However, Kalabuchov (1928) found that in the northern Caucasus area, insects comprised 95% of the stomach contents of two species of hedgehog— the Long-eared hedgehog (*Hemicchinus auritus*) and the Eastern hedgehog (*Erinaceus roumanicus*). Bibikov (1957), also working in the northern Caucasus examined the stomach contents of ten Long-eared hedgehogs and found that they had been feeding mainly on insects too. By contrast, Ch'eng-Chao Liu (1937) in Peiping, found that 95% of the stomach contents of 47 Chinese hedgehogs consisted of maggots.

If any conclusion can be drawn from a comparison of these observations it must be that New Zealand animals rely more on slugs and snails, and less on insects for their main food supply. This is probably not because of any choice on the part of the hedgehog but rather that other sources of food are more readily available to them.

CONCLUSIONS

In the Wellington province hedgehogs have a varied diet. The main food items in suburbs of towns are slugs, millipedes, and snails; on pasture land slugs and moth larvae; in sand dunes snails, millipedes, and, frogs.

Beetles and spiders are frequently eaten but seldom contribute much to the bulk of the diet. Other items, such as earthworms, earwigs, wetas, cicada nymphs are unimportant. Young leaves and succulent buds of clover appear to be intentionally sought after but as these do not appear to be digested, the significance of this habit is unclear.

Millipedes and slugs are eaten throughout the year; snails are eaten most frequently during spring and moth larvae eaten in large quantities durng the autumn.

No evidence was found of hedgehog predation on ground nesting birds in the area studied.

There is a suggestion that New Zealand hedgehogs may depend less than European animals on insects as their main sources of food.

REFERENCES

AXEL, H. E., 1956: Predation and Protection at Dungeness Bird Reserve. *Brit. Birds 49* : 193-212.

BALHAM, R. W., 1949: Some Ecological Studies of the Waterfowl in the Manawatu District of New Zealand. *Thesis for M.Sc.* (in Victoria Univ. of Wellington Library).

————, 1952: Grey and Mallard Ducks in the Manawatu District, New Zealand. *Emu 52* : 163-91.

BARRET-HAMILTON, G. E. H.; HINTON, M. A. C., 1910-21: "A History of British Mammals". Part 7. Gurney and Jackson, London.

BATE, DOROTHEA, 1904: The Mammals of Cyprus. *Proc. zool. Soc. Lond.* : 341-9.

BIBIKOV, D. I., 1956: Biological Observations on the Long-eared Hedgehog (*Erinaceus auritus* Gm.) as a Reservoir of Leptospirae. *Zool. Zh. 35* : 159-64 (In Russian: translation at Animal Ecology Section, D.S.I.R.).

BROCKIE, R. E., 1957: The Hedgehog Population and the Invertebrate Fauna of the West Coast Sand Dunes. *Proc. N.Z. ecol. Soc. 5* : 27-9.

BULL, P. C., 1953: Hedgehogs and Ground-nesting Birds. *Annu. Rep. orn. Soc. N.Z. 1* : 32.

CH'ENG-CHAO LIU, 1937: Notes on the Food of Chinese Hedgehogs. *J. Mammal. 18* : 355-57.

COTT, H. B., 1951: The Palatability of the Eggs of Birds: Illustrated by Experiments on the Food Preferences of the Hedgehog (*Erinaceus europaeus*). *Proc. zool. Soc. Lond. 121* : 1-42.

HERTER, K., 1938: Die Biologie der Europäischen Igel. *Zbl. Kleintierk. 14(b)*.

KALABUCHOW, N. J., 1928: Uber die Nahrung des Igels im Nord-Kaukasus und in der Ukraine. *Mitt. Nordkaukas. Pflanzenschutzstation Rostow. 6* : 62-8 (Not seen, quoted in Herter, 1938).

LANCUM, F. H., 1947: "Wild Animals and the Land". Crosby Lockwood and Son Ltd., London.

LINDEMANN, W., 1951: Zur Psychologie der Igels. *Z. Tierpsychol. 8* : 224-51.

MIDDLETON, A. D., 1935: Factors Controlling the Population of the Partridge (*Perdix perdix*) in Great Britain. *Proc. zool. Soc. London.* : 795-815.

RITCHIE, J., 1931: "Beasts and Birds as Farm Pests". Oliver and Boyd, Edinburgh and London.

WESTERSKOV, K., 1955: The Pheasant in New Zealand. *N.Z. Dept. internal Affairs, Wildlife Publ. 40*.

WODZICKI, K., 1950: Introduced Mammals of New Zealand. *N.Z. Dep. sci. industr. Res. Bull. 98* : 55-64.

SOME FEATURES OF THE BENTHIC ENVIRONMENT
IN COOK STRAIT

By D. E. Hurley, New Zealand Oceanographic Institute, Department
of Scientific and Industrial Research, Wellington

Summary

Underwater photographs taken during investigations on the nature of the sea-
floor in Cook Strait, New Zealand, are of interest in interpreting the ecology of
the outer sublittoral benthic communities. The more important photographs are
reproduced with commentary and discussion. Aggregations of ophiuroids shown
in several photographs are similar to concentrations of ophiuroids reported from
the North Atlantic Ocean.

Introduction

During May 1958, members of the staff of the New Zealand Oceano-
graphic Institute and the State Hydro-Electric Department carried out
investigations from N.Z.G.S. *Matai* on the nature and topography of the
seafloor in Cook Strait in connection with a proposed underwater power
cable. Underwater photographs taken give valuable information on outer
sublittoral* benthic communities in Cook Strait, enabling many of the
organisms present to be identified to a generic and even specific level.
Dredgings in the same area have confirmed some of the deductions
and identifications made from the photographs.

The photographs were taken by Mr G. F. T. Clacy of the State
Hydro-Electric Department, with an underwater camera arrangement
developed for the New Zealand Oceanographic Institute by Mr Clacy
in consultation with the Institute and with Mr S. N. Beatus, of the
Photographic Section, D.S.I.R. Laboratory and harbour tests and cali-
bration of the equipment were carried out by Messrs Clacy and Beatus
and Mr E. J. Thornley, also of Photographic Section, D.S.I.R., where
the photographs were developed.

---

*The term "outer sublittoral" is used as proposed by the Committee on Marine
Ecology and reported in Hedgpeth (1957). They define the seafloor from low
tide level to the edge of the continental shelf as "sublittoral". This is divided
into "inner sublittoral" from low tide to the boundary between the photic and
aphotic zones, and "outer sublittoral" from there to the edge of the shelf.

The equipment is basically a large metal tripod bearing swivelling pressure chambers containing camera and flash units, with lever release gear arranged to trip the camera on contact with the seafloor. An adjustable re-cycling device allows the camera to be triggered and re-set each time contact is made with the bottom.

The camera is a Robot 35 mm unit with 1·9 Schneider Kreuznach Xenon lens of 40 mm focal length, installed in an adjustably swivelling cylindrical pressure chamber of 6 in. inner diameter at a height of 5 ft 6 in. The flash unit is a "Matador" Ultrablitz Photoflash Unit in a separate swivelling chamber 2 ft below the camera unit. The original power unit of the flash has been replaced by a bank of 6 D.E.A.C. cells (8 volts), driving two pulsating transistors in push-pull arrangement to deliver 500 volts to charge the capacitors. The units are synchronized by protected sealed cable joining the back-plates of the two chambers.

The flash chamber has a 1 in. thick perspex window and the camera unit a 1 in. glass window. They are designed to operate safely to a depth of 200 fathoms and to withstand pressures to a collapsing depth of 375 fathoms. They have been tested to a pressure of 810 lb/sq. in.

The lever release operates when a suspended plummet touches the bottom and operates a counterpoised lever which has a permanent magnet mounted on the face opposing the back of the camera housing. The device is designed to operate positively when the external magnet approaches within 1 in. of the sensing device within the housing. Only one exposure is made each time the tripod is lowered on to the bottom and the camera and flash automatically re-set themselves with a $2\frac{1}{4}$ min. charging time for the flash capacitors. The time between the operation of the sensing device and release of the camera and flash may be varied up to 30 sec. and the batteries can operate for as much as 8 hr at a time. The circuit and time release have been described elsewhere (Anon., 1957).

The flash is rated at 100 Joules and the camera is set at f. 8 for 9 ft using Agfa ISS or Ilford FP3 film. The shutter is nominally set at 1/50th of a second but the exposure is, of course, that of the much shorter duration of the flash.

The area shown in each photograph is approximately 10 sq. ft (1m²) but in some the camera has obviously been set at a slightly greater angle from the vertical than others and covers a somewhat larger area.

Description

The location of the various stations is shown in Fig. 1.

NZOI Station C.119

Lat. 41° 18′ 45″ S; long. 174° 32′ 30″ E; depth 94 fathoms; time 1022 hr; date 17/5/58.
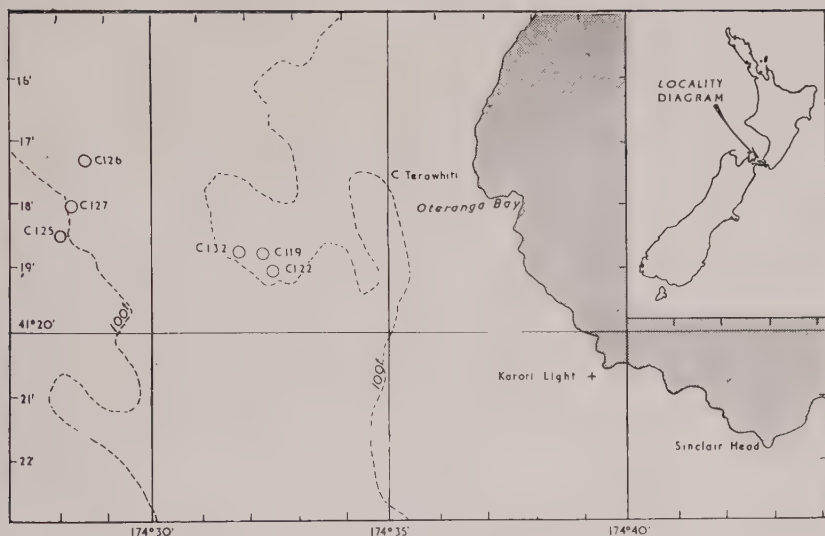
FIG. 1.—Cook Strait Narrows showing station positions.

The photographs from Station C.119 and C.122 show specimens of a tunicate, *Pyrosoma atlanticum atlanticum* Person, some actively swimming just above the bottom, others resting on it. The seafloor at C.119 is of small cobbles, relatively free from sediment, suggesting a reasonably strong and persistent current. There are also numerous white streaky objects, perhaps worm tubes.

NZOI Station C.122

Lat. 41° 19′ 04″ S; long. 174° 32′ 36″ E; depth 90 fathoms; time 1505 hr; date 18/5/58.

The bottom is of medium-sized cobbles. *Pyrosoma* are present and amongst the cobbles there are numerous white objects which could possibly be empty molluscan shells but are more probably pebbles covered with encrusting bryozoan.

NZOI Station C.125

Lat. 41° 18′ 29″ S; long. 174° 28′ 10″ E; depth 101 fathoms; time 0945 hr; date 18/5/58.

The photograph from C125 (Fig. 2) reveals an abundance of ophiuroids, which are almost certainly *Ophiocoma bollonsi* Farquhar. The floor is of medium to large cobbles, partially buried in fine sediment, with occasional clumps or strands of a plant-like growth which dredging samples indicate to be hydroid rather than bryozoan.

Fig. 2.—Photograph from Station 125 with ophiuroids and brachiopods prominent.

There is a probable worm tube to the lower left of centre, and at the same level on the right a small colony of Brachiopoda, probably *Liothyrella neozelanica* Thomson. At bottom right is a sponge of similar appearance to *Siphonochalina*. Various molluscan shells are visible, especially in the upper half of the photo, but the only identifiable ones are two separated valves of *Chlamys gemmulata* (Reeve) at upper centre and bottom centre, and a live *C. gemmulata* at upper right. Immediately below the latter and slightly to the left is what appears to be a further live *C. gemmulata* with open valves.

NZOI Station C.126

Lat. 41° 17′ 16″ S; long. 174° 28′ 45″ E; depth 141 fathoms; time 1025 hr; date 18/5/58.

Fig. 3.—Photograph from Station 126 showing ophiuroids and *Chlamys*.

The fauna at Station C.126 (Fig. 3) is similar to that at Station C.125 but sparser. *Ophiocoma* is again dominant, and three live *Chlamys gemmulata* are obvious (upper centre and lower left of centre). A gastropod of the Turritellidae, probably *Maoricolpus roseus* (Q. & G.) and almost certainly an empty shell, is visible at extreme bottom left. Sertularians or branching bryozoans are scattered throughout in sparse tufts.

The bottom is again of medium to large cobbles with less sediment matrix than at Station C.125.

NZOI Station C.127

Lat. 41° 18′ 05″ S; long. 174° 28′ 21″ E; depth 117 fathoms; time 1120 hr; date 18/5/58.
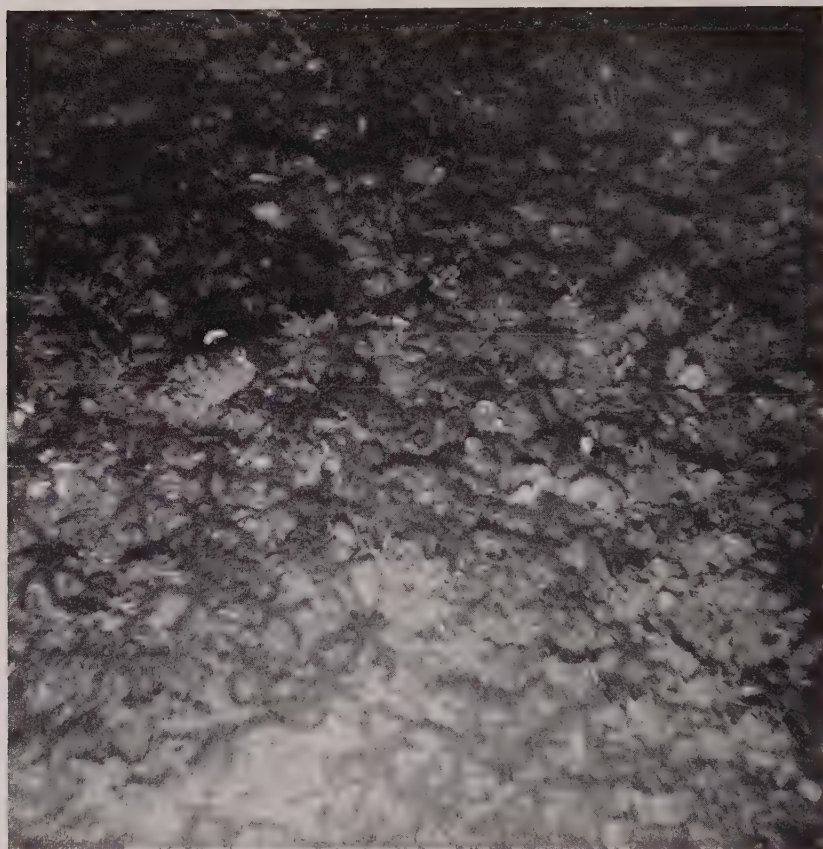
Fig. 4.—Photograph from Station 127 with ophiuroids covering area.

The seafloor at Station C.127 (Fig. 4) is littered with great numbers of *Ophiocoma*, more densely than at Station C.125, although it would appear that the camera position was tilted so that this view covers a greater area than Figs 2 and 3. Tufts of sertularian or bryozoan are numerous, and a *Chlamys gemmulata* is visible (centre right). Two whitish objects to the lower left of this *Chlamys* may be small sponges. A gasteropod, resembling *Maoricolpus roseus,* is visible upper left of centre. Other white objects scattered across the area suggest mollusc shells.

The bottom is of medium cobbles with much more sedimentary matrix visible than in the previous two photographs.

NZOI Station C.132

Lat. 41° 18′ 43″ S; Long. 174° 31′ 54″ E; depth 92 fathoms; time 1527 hr; date 18/5/58.

Fig. 5.—Photograph from Station 132. "Snake-tail" ophiuroid *(Pectinura macu-lata)*, and sea anemones prominent.

At Station C.132 (Fig. 5) a large ophiuroid, probably *Pectinura maculata Verrill*, is visible in the centre of the photograph. From the profile view of a cluster at upper centre, the white objects on the large stones can be identified as sea anemones. Tufts of hydroid are present throughout. Larger white masses on the stone at bottom centre are most probably colonial ascidian or sponge, or, possibly, encrusting bryozoan.

The seafloor here is of large cobble stones with a pebbly matrix.

Discussion

These photographs are of considerable value in interpreting the benthic ecology of the area, known otherwise only from dredgings. Associations indicated by dredging are confirmed and clarified by these records of undisturbed fauna in the natural state.

Pectinura maculata is extremely abundant on the oyster beds in Foveaux Strait, New Zealand (Fleming, 1952; Fell, 1952), and *Ophiocoma bollonsi,* once considered rare, has been taken in great numbers in Cook Strait by members of the Zoology Department, Victoria University of Wellington (Fell, 1958). Recent dredgings by the New Zealand Oceanographic Institute confirm the abundance of *O. bollonsi* in Cook Strait.

It would appear to be relatively easy to estimate the numbers of ophiuroids in Figs 2 to 4, but in practice it is surprisingly difficult. The best count of Fig. 3 is approximately 40 specimens within the area of the photograph, but in Figs 2 and 4 indistinct outlines, shadows, natural camouflage, and the occurrence of specimens on top of one another render counting extremely difficult. A rough estimate indicates approximately twice as many specimens of *Ophiocoma* per unit area in Fig. 2 as in Fig. 3, and four to five times as many in Fig. 4.

According to Ladd (1957) "most echinoderms in the seas of today are gregarious; the habit of living closely together in large numbers goes back to early geological time." Ladd (1957) published photographs of fossil gregarious free-swimming crinoids (*Uintacrinus socialis*) from Kansas Cretaceous rocks; of concentrations of living starfish in 110 ft of water in Block Island Sound, U.S.A., photographed by Ewing and Tirey; of the Devonian starfish, *Palacaster,* from Saugerties, New York; of Cretaceous brittlestars (*Ophioglypha graysonensis*) from Texas; and of living brittlestars from San Diego Trough, off California, in 600 fathoms. Hyman (1955) reported an observation of Fedotov (1924) of gorgonocephalids living in aggregations in the Kola Fjord "on rocky shelves swept by plankton-bearing currents".

Underwater photographs from the North Atlantic have also revealed great concentrations of ophiuroids. Vevers (1951, 1952), Barnes (1955), and McIntyre (1956) have shown that *Ophiothrix fragilis* and, to a lesser extent, *Ophiocomina nigra* aggregate in this manner.

Except for the absence of algae, the fauna shown in Figs 2 to 5 is basically similar to that of an inner sublittoral region with a strong current. At Portobello, Otago Harbour, for example, anemones and colonial ascidians may be found on large stones, sertularians " at times more than a metre high", serpulid worms, encrusting and branching bryozoans, and the sponge *Siphonochalina* (Batham, 1956).

The portions of the floor of Cook Strait discussed here are, in fact, subjected to relatively fast-flowing tidal currents. Mr A. E. Gilmour of the New Zealand Oceanographic Institute has measured the tidal flow in this part of Cook Strait at up to $\frac{3}{4}$ knot at a distance of 10 in. above the bottom (pers. comm.). Dr R. W. Burling (pers. comm.) has calculated that at 2 in. above the bottom this would still be in the range of $\frac{1}{4}$ to $\frac{1}{2}$ knot.

From his examination of the stomachs of *Ophiocoma bollonsi* from Victoria University of Wellington Station No. 48 where the nature of the bottom is noted as "? sand", Professor H. B. Fell (pers. comm.) has confirmed that they do contain sand, indicating the probability that *O. bollonsi* is primarily a detritus feeder rather than a predator. This is consistent with the ecological situation where detritus would be available to the animals from the sediment matrix and in addition, and probably more important, from the continual current sweeping past them. This does not rule out the possibility of occasional carnivorous feeding when the opportunity is presented.

This is not unusual with ophiuroids. Hyman (1955) stated that "the ophiuroids in general combine the ingestion of bottom material with carnivorous feeding", and Thorson (1957) stated that *Amphiura* is "able to feed on animal food when it is available and on detritus when no prey is found".

In view of these indications from the nature of the fauna as shown in the photographs and from the exposed and partially exposed nature of the cobbles, as well as from actual measurements, that this is a continually current-swept region, the following comments of Vevers (1952) on a similar situation are of interest:

"The permanent nature of these brittle-star populations suggests that they rely for their food supply more on a steady flow of suspended matter than on a settled bed of living or dead organic matter. It is possible that much of this suspended matter is carried back and forwards over the *Ophiothrix* bed by the tidal streams, and the position of the Looe and Rame beds at 5 and 4 miles respectively from the coast would favour this. The tidal streams in the neighbourhood of Eddystone are well known, and they would also tend to gather suspended matter and carry it over the massed brittle-stars with their food-collecting net of tangled arms. . . . It is suggested that . . . the crowded beds are on localities where this is likely to occur".

The significant features of the fauna shown in these photographs, then, are those of a typical filter or detritus feeding community in an outer sublittoral cobble bottom region where there is a considerable seafloor current. In these conditions, ophiuroids are the most striking feature of the fauna. The persistence with which concentrations of ophiuroids appear in underwater photographs, both here and elsewhere, supports the belief that aggregation in ophiuroids is not a manifestation of specialized and short-term behaviour such as spawning, but is an aspect of the normal behaviour of a naturally gregarious group of animals, and directly related to their manner of feeding.

Acknowledgements

Thanks are expressed to Professor H. B. Fell of the Zoology Department, Victoria University of Wellington, for identification of the Ophiuroidea and other helpful information, and to Dr R. K. Dell of the Dominion Museum for identification of Mollusca and Brachiopoda. Mr A. E. Gilmour and Dr R. W. Burling of the New Zealand Oceanographic Institute supplied information on bottom currents in Cook Strait.

References

Anon, 1957: A Magnetically-operated Relay. *Radio Elect. Rev. (N.Z.) 12 (7)* : 23-6, figs 1-4.

Barnes, H., 1955: Underwater Television and Research in Marine Biology, Bottom Topography and Geology. *Dtsch. Hydrogr. Z. 8 (6)*: 36, figs 1-49, 2 tables.

Batham, E. J., 1956: Ecology of Southern New Zealand Sheltered Rocky Shore. *Trans. roy. Soc. N.Z., 84 (2)* : 447-65, pls. 29-31, 9 text-figs.

Fedotov, D., 1924: Biologie und Metamorphose von *Gorgonocephalus. Zool. Anz. 61.*

Fell, H. B., 1952: Echinoderms from Southern New Zealand. *Zool. Publ. Vict. Univ. N.Z. 18* : 1-37, figs 1-27.

————, 1958: Deep-Sea Echinoderms of New Zealand. *Zool. Publ. Vict. Univ. N.Z. 24* : 1-40, pls 1-5.

Fleming, C. A., 1952: A Foveaux Strait Oyster-bed. *N.Z. J. Sci. Tech. B. 34 (2)* : 73-85, figs 1-4.

Hedgpeth, Joel W., 1957: Classification of Marine Environments. *Mem. geol. Soc. Amer. 67 (1)* : 17-27, figs 1-3. Also: *Ibid. 67 (2)* : 93-100, figs 1-3 (abridged).

Hyman, Libbie Henrietta, 1955: Echinodermata: The Coelomate Bilateria, *in* "The Invertebrates". Vol. 4 : vii & 763 pp., 280 figs. McGraw-Hill Book Co. Ltd., New York.

Ladd, Harry S., 1957: Paleoecological Evidence. *Mem. Geol. Soc. Amer. 67 (2)* : 31-66, 9 pls.

McIntyre, A. D., 1956: The Use of Trawl, Crab, and Camera in Estimating Marine Benthos. *J. Mar. biol. Ass. U.K. 35* : 419-29, pls 1-4, 1 text-fig., 3 tables.

THORSON, GUNNAR, 1957: Bottom Communities (Sublittoral or Shallow Shelf). *Mem. Geol. Soc. Amer.* 67 (1) : 461-534, figs 1-20.

VEVERS, H. C., 1951: Photography of the Sea Floor. *J. Mar. biol. Ass. U.K., 30 (1)* : 101-111, 1 pl., 2 text figs, 2 tables.

———, 1952: A Photography Survey of Certain Areas of Sea-floor near Plymouth. *J. Mar. biol. Ass. U.K., 31 (2)* : 215-22, pl. 1, text-figs 1-2.

CONTRIBUTIONS TO A CHROMOSOME ATLAS OF THE NEW ZEALAND FLORA—2

MISCELLANEOUS FAMILIES

By J. B. Hair and E. J. Beuzenberg, Botany Division, Department of Scientific and Industrial Research, Christchurch

Summary

Documented chromosome numbers are provided for 27 species, two varieties, and a reputed hybrid, in 22 genera (from 18 families) of New Zealand plants.

TABLE 1.—*Documented Chromosome Numbers of New Zealand Plants: Miscellaneous Families.*

Species	n	2n	Source	Herb. No.
AIZOACEAE				
Disphyma australe (Sol.) J. M. Black	18	36	Oteranga Bay, Wellington	100491
Tetragonia tetragonioides (Pallas) Kuntze	16	—	Ocean Beach, Whangarei Heads	101229
T. trigyna Banks et Sol. ex Hook. f.	48	—	Paraparaumu	100490
COMPOSITAE				
Brachyglottis rangiora Buch.	30	—	Otari Gardens, Wellington	200225
B. repanda Forst.	30	—	Otari, Wellington	200224
CORNACEAE				
Corokia buddleoides A. Cunn.	9	—	Kaitaia District*	200226
var. *linearis* Cheesem.	9	—	Otari Gardens, Wellington	200227
C. cheesemanii Carse†	9	—	Otari Gardens, Wellington	200230
C. cotoneaster Raoul	9	18	Waiau, North Canterbury*	200229
C. macrocarpa T. Kirk	9	—	Chatham Islands*	200228
Griselinia littoralis Raoul	18	36	Otari Gardens, Wellington	200231
G. lucida Forst. f.	18	—	Otari, Wellington	200232
HYPERICACEAE				
Hypericum gramineum Forst. f.	8	—	Trotters Gorge, Palmerston, Otago	100730
H. japonicum Thunb.	8	—	Lake Lyndon, Canterbury	100941

Table 1.—*Continued.*

Species	n	2n	Source	Herb. No.
ICACINACEAE				
Pennantia corymbosa Forst.	25	—	Riccarton Bush, Christchurch	200234
LINACEAE				
Linum monogynum Forst. f.	42	—	Cape Terawhiti, Wellington	100049
			Awatere River, Marlborough	200238
MONIMIACEAE				
Hedycarya arborea Forst.	57	—	Otari, Wellington	200239
Laurelia novae-zealandiae A. Cunn.	22	—	Otari, Wellington	200241
MYOPORACEAE				
Myoporum laetum Forst. f.	54	—	Otari Gardens, Wellington	200242
var. **decumbens** Simpn.	54	—	Three Kings Island*	200243
PAPILIONACEAE				
Clianthus puniceus (G. Don) Sol. ex Lindl.	16	32	Botanic Gardens, Christchurch	200235
PASSIFLORACEAE				
Tetrapathaea tetrandra (Sol.) Cheesem.	12	—	Riccarton Bush, Christchurch	200244

Family / Species	n	2n	Locality	Number
PRIMULACEAE				
Samolus repens (Forst.) Pers.	26	—	New Brighton, Canterbury	100295
			Oteranga Bay, Wellington	100542
PROTEACEAE				
Persoonia toru A. Cunn.	14	28	Botanic Gardens, Christchurch	200245
Knightia excelsa R.Br.	14	28	Otari, Wellington	200246
RHAMNACEAE				
Discaria toumatou Raoul	11	—	Botanic Gardens, Christchurch	200247
SAPINDACEAE				
Dodonaea viscosa Jacq.	14	28	Otari Gardens, Wellington	200248
SCROPHULARIACEAE				
Mimulus repens R.Br.	—	20	Lake Ellesmere, Canterbury	100733
STACKHOUSIACEAE				
Stackhousia minima Hook. f.	10	20	Balmoral, North Canterbury	101286
			Lake Lyndon, Canterbury	100954
STYLIDIACEAE				
Oreostylidium subulatum (Hook. f.) Berggr.	15	30	Near Lake Brunner	101461
TILIACEAE				
Entelea arborescens R.Br.	16	—	Otari Gardens, Wellington	200250

*Grown on at Otari Gardens, Wellington.   †Reputed natural hybrid between *C. buddleoides* and *C. cotoneaster*.

Description of Figures.

Unless otherwise stated, all figures are of first metaphase of meiosis.   × 1500.

Fig.   1.—*Disphyma australe* (n = 18), 18^{II}.

Fig.   2.—*Tetragonia tetragonioides* (n = 16), 15^{II} 2^{I}.

Fig.   3.—*T. trigyna* (n = 48), 48^{II}.

Fig.   4.—*Brachyglottis rangiora* (n = 30), diakinesis, 30^{II}

Fig.   5.—*Corokia buddleoides* (n = 9), 9^{II}.

Fig.   6.—*C. buddleoides* var. *linearis* (n = 9), 9^{II}.

Fig.   7.—*C. cheesemanii* (n = 9), 9^{II}.

Fig.   8.—*C. cotoneaster* (n = 9), 9^{II}.

Fig.   9.—*C. macrocarpa* (n = 9), 9^{II}.

Fig. 10.—*Griselinia littoralis* (n = 18), 18^{II}.

Fig. 11.—*G. lucida* (n = 18), 18^{II}.

Fig. 12.—*Linum monogynum* (n = 42), 42^{II}.

Fig. 13.—*Clianthus puniceus* (n = 16), 16^{II}.

Fig. 14.—*Tetrapathaea tetrandra* (n = 12), 12^{II}.

Fig. 15.—*Samolus repens* (n = 26), 26^{II}.

Fig. 16.—*Mimulus repens* (2n = 20), mitotic metaphase.

Fig. 17.—*Stackhousia minima* (n = 10), 10^{II}.

Fig. 18.—*Oreostylidium subulatum* (n = 15), 14^{II} 2^{I}.

Fig. 19.—*Entelea arborescens* (n = 16), 16^{II}.

DESCRIPTION OF FIGURES.

Unless otherwise stated, all figures are of first metaphase of meiosis. $\times$ 1500.

FIG. 20.—*Hedycarya arborea* (n = 57), 57^{II}.

FIG. 21.—*Laurelia novae-zealandiae* (n = 22), 22^{II}.

FIG. 22.—*Persoonia toru* (n = 14), first pollen grain mitosis.

FIG. 23.—*Knightia excelsa* (n = 14), 14^{II}.

FIG. 24.—*Pennantia corymbosa* (n = 25), 25^{II}.

FIG. 25.—*Myoporum laetum* (n = 54), diakinesis, 2^{VI} 3^{IV} 42^{II}. See Fig. 30.

FIG. 26.—*Hypericum gramineum* (n = 8), 8^{II}.

FIG. 27.—*H. japonicum* (n = 8), 8^{II}.

FIG. 28.—*Discaria toumatou* (n = 11), 11^{II}.

FIG. 29.—*Dodonaea viscosa* (n = 14), 14^{II}.

20
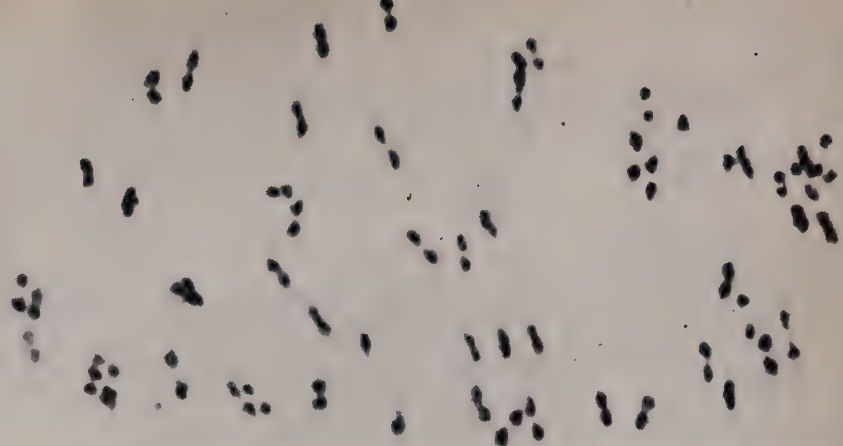
22
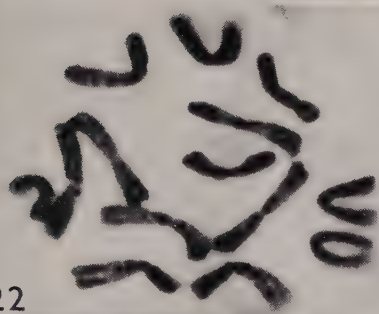
2
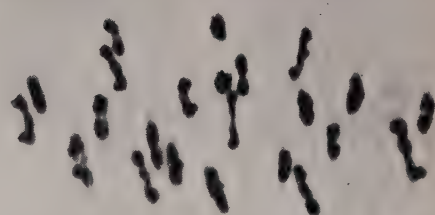
23
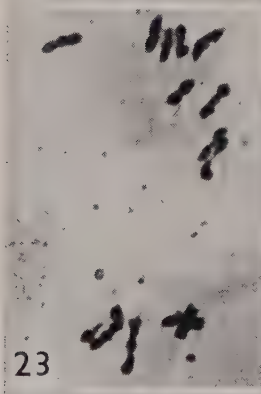
24

2
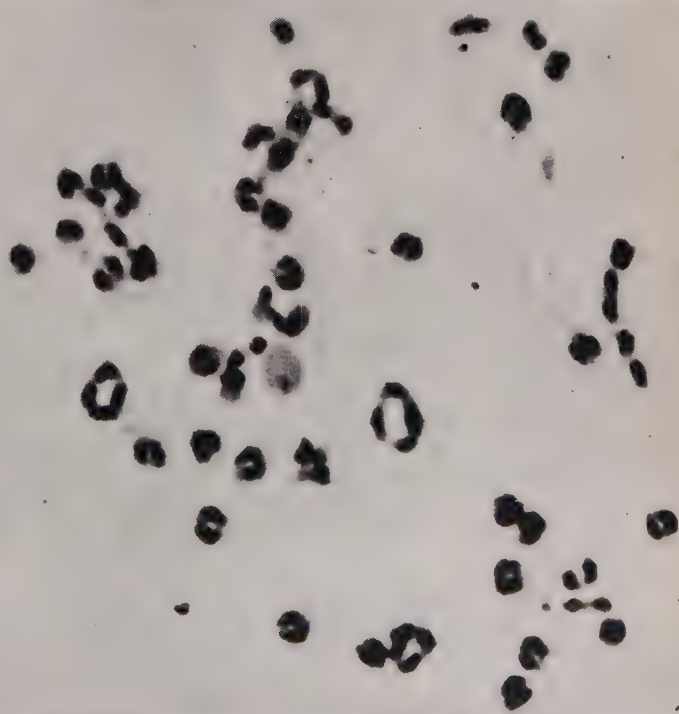
FIG. 30.—*Myoporum laetum* (n = first metaphase of meiosis, 2^{VI} 4^{IV} 1^{III} 38^{II} 1^{I}.

FIG. 31.—*Brachyglottis repanda* (n = 30), 30^{II}.

JOURNAL OF GEOLOGY AND GEOPHYSICS

Volume 2, No. 1, February 1959

CONTENTS

NEW ZEALAND

JOURNAL OF AGRICULTURAL RESEARCH

Volume 2, No. 1, February 1959

CONTENTS

NEW ZEALAND JOURNAL OF SCIENCE

Vol. 2, No. 1, March, 1959

CONTENTS OF THIS ISSUE